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The Philosophical Frontiers of Physics

A DISSERTATION

SUBMITTED TO THE FACULTY OF PHILOSOPHY OF THE CATHOLIC UNIVERSITY
OF AMERICA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

BY

VINCENT EDWARD SMITH, M.A.

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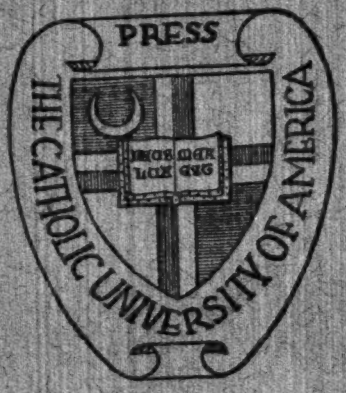

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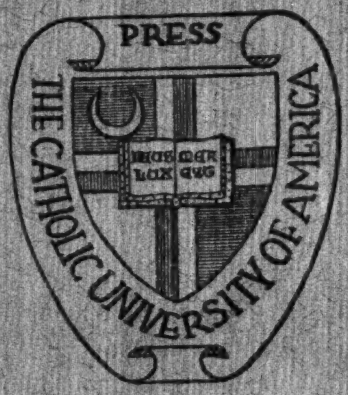

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TO
THE MOST REV. JOHN T. McNICHOLAS, O.P., S.T.M.
ARCHBISHOP OF CINCINNATI
SCHOLAR AND PATRON OF SCHOLARSHIP
THE FOLLOWING PAGES
ARE THANKFULLY DEDICATED

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PREFACE

This dissertation, projected before the author's entry into military service, is published now, at a time when the current of science in the post-war world has given fresh, heavier charges to the problem of empirical knowledge. No longer does the scientific method (if indeed it ever did) present a mere classroom problem for specialized students who major in philosophy. The fate of man's civilization is bound up in his attitude toward science. His whole hope seems to rest in the stand he takes toward the method of science and toward the material means which the method procures. If this stand is to be firmly footed and is not to be a mere whim that might live today but leave man trembling before tomorrow, then the vast reality of science, in the value of its method and the meaning of its conclusions, must be examined in a considered, rational, certifying way. A pace along this long, rugged, complicated road of examining modern science is the purpose of the following pages.

It did not take an atom bomb, radar, or the VT fuse to awaken philosophers to the problem of empirical knowledge. There were, at the very dawn of the modern age, the intellectual atoms of Cartesian rationalism and British empiricism. These exploded so forcefully that philosophy, ever since, has been busied with the ensuing chain-reaction. Modern philosophy is very largely the philosophy of science. It has largely become the study of a method, as though method could ever be studied apart from matter. It is largely the science of the sciences, as though we could ever study knowledge apart from its object. The result has simply been the meaningless, circular rhythm of scientific method applied to scientific method. It is as though technique could ever be studied away from art, form without matter, and movement apart from a thing moved. Such approaches to the physical sciences have not been too successful. They have not been intellectually sound because of their Cartesian concept of method separate from matter. They have not been practically prosperous because they lead to

intellectual skepticism, moral indifference, and emotions of fear and anxiety. For example, if we examine method apart from matter, then we must examine the method of applying the method to matter. So on and on.

The present study does not aim to criticize the so-called scientific method as an abstract thing. As far as writing space and non-mathematical language would allow, technical procedures and technical data have been sketched to exemplify scientific method, and the last two chapters are devoted wholly to the material furnished by science—devoted, namely, to the scientific method in action. The desire to present the procedures of science as materially as possible, as seen by both scientist and philosopher, has in some chapters the handicap that much of the text is expository and little comparative space left for criticism. But a more completely critical procedure would not have provided room for proper emphasis on what the scientist actually does. Whatever philosophical comments and criticisms have entered into these earlier chapters were deemed necessary to avoid misunderstanding or to answer immediate problems raised by the expository material. If the result has been in some cases a repetition, in a later and more elaborate form, of what these earlier chapters have said in part, it can only be replied that a well-rounded treatment of the various aspects of the vast subject of science must necessarily result in some overlapping.

Exposition is indeed not outside the science of philosophy. In many cases, to define and describe a thing accurately is to put it in its proper place so that further critical questions are either unnecessary or matched by self-evident answers. The common notion of our age, that direct demonstration is necessary for every truth, cuts away the beginning and end of knowledge, leaving such a purely scientific method hanging in a meaningless vacuum. Physics would simply have to cease existing if this notion were ever carried out. Happily, despite the protest of positivism, every physicist implicitly accepts something outside the scientific method, namely, self-evidence. Without it, the physicist, as a scientist and as a man, would be intellectually paralyzed. If we are told that the scientific method is validated by its fruits, then we may ask how this pragmatic norm is justified in itself. At last we are plunging once more into the bottomless, meaningless pits of the infinite regression.

One of the great milestones of our journey is passed when we get a sound idea of what the physicist is doing. So much of the literature in contemporary philosophy is the product of *a priori* philosophers, striving to deduce science, or *a priori* scientists, seeking to absorb philosophy. Prejudiced from the outset, they fail to describe what the scientist is really doing, and any estimate, on this basis, of scientific method must suffer correspondingly.

Those who are in fact or in spirit positivistic would reject much of the following pages as containing "'metaphysical presuppositions." Metaphysics, yes, but presuppositions, no! For there is a method of knowledge, outside the scientific method, in the science of philosophy which proceeds by entitative analysis of experience and which gives rise to metaphysics. In the branch of philosophy which deals with the possibility of our knowledge of being, the method of reflection is used, reflection—the self-evident, immediate fact—in which man, being the subject and object of his own actions, escapes from the infinite regression demanded by pure scientific method.

Reflection is an undeniable, self-evident fact, and its fruits, rooted in experience, are valid knowledge. By reflection, philosophy can justify its own self and its own method, whereas the mediating, discursive method of physics slopes toward a meaningless infinity. Without something definite, non-atomistic, and non-circular, the method of physics is itself a meaningless question and the product of mere presuppositions. If everything is mediate, as physics says, then there is nothing that is. Man may just as well take in the shingle of all human knowledge, because the world has done so with its being-ness, leaving only a vacuum as an object of knowledge.

The bibliography is quite selective. In the impossibility of citing the long list of books and articles on the implications of science, the bibliography has been sifted to include only works which bear substantially on the subjects treated in the text, and unless more than a single writing is cited at length or for some other equally

valid reason, only one work representative of a given author or given school of thought has been mentioned.

The author is deeply grateful to the Very Rev. Dr. Ignatius Smith, O.P., dean of the School of Philosophy at Catholic University, whose kind and scholarly interest was inspiringly felt not only in the matter of critically assisting this dissertation but also in the more general questions and problems of student life. Special thanks are due to the Rev. Dr. John K. Ryan, under whose guidance this dissertation was written. Not only did he help by direct advice on the dissertation, but his weekly seminar was a valuable stimulus in many ways. To the other readers of the manuscript, a deep debt is likewise owed for their positive contribution. They are Dr. Rudolf Allers and the Rev. Dr. William J. McDonald, of the faculty of the School of Philosophy at Catholic University; the Rt. Rev. Msgr. James W. O'Brien, rector of Mt. St. Mary Seminary, Norwood, Ohio; the Rt. Rev. Msgr. Walter J. Roddy, rector of St. Gregory Seminary, Cincinnati; and my wife, Virginia Beck Smith.

CHAPTER I

Physics and Philosophy—Disputed Frontiers

I

The frontiers of physics and philosophy are a disputed territory in contemporary thought. The views on the subject are remarkable both for number and for kind. Not only do present-day philosophers, claiming the right to criticize physics, disagree as to its meaning and value; but scientists themselves have in recent years been turning out philosophies of their own making. The diverging views of contemporary writers tend to complicate more and more a problem already great enough by the mere historic fact of the separation of science and philosophy. As divorce works hardships on the children of a marriage, so the divorce of science and philosophy has left its mark not only on the thinkers of the two fields but upon the whole intellectual life of modern man.

It is in history that the problem began; only in the light of history can it be fully analyzed and answered. The Greeks, believers in the harmony of nature and in the unity of knowledge, studied the material world as a unit. Their point of view was inherited by their intellectual descendants in the medieval schools. The *Physica* of Aristotle and Aquinas employs the phenomenal world as a stepping-stone to a knowledge of its underlying substances and its ultimate causes. On the other hand, the physics of the present day seeks knowledge only of the interrelations of the phenomena themselves.[1] As Aristotle wrote: "Knowledge is the object of our inquiry, and men do not think they know a thing till they have grasped the 'why' of it (which is to grasp its primary cause)."[2]

[1] Cornford, F. M., "Greek Philosophy and Modern Science," in *Background to Modern Science,* edited by J. Needham and W. Pagel, New York, 1938, p. 12.

[2] *Phys.,* 194b, 18ff. The English translation of Aristotle here and hereafter is taken from *The Works of Aristotle,* edited by W. D. Ross, Oxford, 1930. Abbreviations in citing Aristotle and Aquinas will be recognized from standard works of each.

The scholastics by no means neglected experiment. Even Aquinas and Duns Scotus, essentially metaphysicians rather than empirical scientists in the modern sense, extol an experimental method.[3] It was not that they loved the relative less but that they loved the absolute more. They refrained from doing what has been done in our own age, viz., to exploit the experimental method as a law unto itself. Their lives and their learning were essentially theocentric.

How much modern science is indebted to the schoolmen for its positive principles of method is a question that remains to be studied in its fullness. Whitehead has summed up the case thus: "It needs but a sentence to point out how the habit of definite exact thought was implanted in the European mind by the long dominance of scholastic logic and scholastic divinity," and "the greatest contribution of medievalism to the formation of the scientific movement" was "the inexpugnable belief that every detailed occurrence can be correlated with its antecedents in a perfectly definite manner, exemplifying general principles."[4] But the debt of modern science to scholastic thought is more than the art of logic and the belief in nature's uniformity. Gilson, in a searching study of the relation of scholastic philosophy to Descartes, who was in many ways the founder of modern philosophy and modern mathematical physics, affirms: "From the beginning, Cartesian physics presented itself to us as a new ferment, working over and assimilating a host of old ideas, so much so that Cartesian metaphysics appeared as what scholasticism becomes in a world which contains only extension and motion."[5] Descartes had studied scholastic philosophy in the college at La Flêche where his courses were patterned on the great systems of the thirteenth century.

[3] Aquinas writes: "Qui sensum negligit in naturalibus incidit in errorem." *In de Trin. Boeth.*, 6, 2. "Ut hoc modo judicemus de rebus naturalibus secundum quod sensus ea demonstrat." *Ibid.* Scotus writes: "De cognitis per experientiam dico quod licet experientia non habeatur de omnibus singularibus, sed de pluribus, nec quod semper sed quod pluries, tamen expertus infallibiliter novit quod ita est quod semper et in omnibus. . . ." *Commentory on the Sentences* I, d. 3, q. 4, n. 9.

[4] *Science and the Modern World*, New York, 1925, p. 17.

[5] Translated from *Etudes sur le Rôle de la Pensée Médiévale dans la Formation du Système Cartésien*, Paris, 1930, p. 143.

Gilson has traced five hundred and eighty-two Cartesian concepts to a scholastic origin.[6]

Francis Bacon, though not so important as Descartes but nevertheless a philosophical patron of experiment, was also influenced by the past. He condemns the syllogism because notions are "improperly and overhastily abstracted from facts, vague, not sufficiently definite, faulty, in short, in many ways,"[7] a possibility which Aristotle himself warned against in his *Topics* and sought to combat by insisting on clear definitions. Bacon therefore rejected Aristotelian logic. He proposed a new system. But his method, like Cartesianism, is not completely new. It is not without its debt to the past. Indeed, his induction by exclusion has its counterpart in the method of definition as found in Plato—a fact which Bacon himself acknowledges.[8] His three Tables—the Table of Essence and Presence, the Table of Deviation or Absence in Proximity, and the Table of Degrees or Comparison—which are designed to help the mind in its inductive process of exclusion—are all based upon a single principle that can be best stated in terms of the third Table: "it necessarily follows that no nature can be taken as the true form, unless it always decrease when the nature in question decreases, and in like manner always increase when the nature in question increases."[9] But though these tables are regarded as historical innovations and have formed the basis for Mill's canons, they have a counterpart in Aristotle who writes: ". . . if an increase of the accident follows an increase of the subject, clearly the accident belongs, while if it does not

[6] *Index Scolastico-Cartésien*, Paris, 1912.

[7] *The Works of Francis Bacon*, ed. Spedding, Ellis, and Heath, London, 1858, vol. 4, p. 49.

[8] "But the induction which is to be available for the discovery and demonstration of the sciences and arts, must analyze nature by proper rejections and exclusions; and then after a sufficient number of negatives, come to a conclusion on the affirmative instances: which has not yet been done or even attempted, save only by Plato, who does indeed employ this form of induction to a certain extent for the purpose of discussing definitions and ideas," *ibid.*, vol. 4, pp. 97-98. But Plato's method is an intellectual analysis and hence not exactly the same as Bacon's crude method which is both theoretically unfounded and impossible in practice, as will be later apparent.

[9] *Ibid.*, vol. 4, p. 137.

follow, the accident does not belong. You should establish this by induction."[10]

It is obvious that Descartes and Francis Bacon, the philosophers of the scientific movement at its origin, did not present completely new systems. Much of the scientific movement is not a new creation. It is an evolution of ideas already present in amoebic form within the body of earlier thought.[11]

But if they were children of scholastic philosophy, Bacon and Descartes were in great measure the philosophical founders of the modern scientific movement in proposing the autonomy of science. Rejecting formal and final causes from knowledge, they opened the way for a division of labor in the study of the cosmos. Empirical science has asserted its dominion over the proximate material and motor causes of the visible world. Scholastics have insisted that the scientist's picture is incomplete. He fails to take form and finality into account.

But the philosophy of modern physics in its historical genesis is not the work only of theorists like Bacon and Descartes. It was the professed physicists and practical experimenters—Leonardo da Vinci, Galileo, Tycho Brahe, Kepler, Newton, and a host of others less renowned—who seemed, by the sheer success of their work, to evince the self-sufficiency of experiment.[12] Leonardo was using and urging experiment before Galileo and Bacon were born. Galileo and Tycho were methodical experimenters. In the work of Kepler and Newton, classical mechanics was furnished with a broad foundation. Physics had not only gained its autonomy in a theoretical sense through Cartesian metaphysics and the rising tide of English empiricism. In a practical way, it seemed able to confute the notion that form and finality are needed to explore

[10] *Top.* 115a, 2 ff.

[11] Even the study of phenomena by the mathematical methods of modern physics is suggested by Aristotle in *An. Post.* 79a, 1 ff. and by Aquinas who writes: "Similiter autem corpus naturale addit materiam sensibilem super magnitudinem mathematicam: et ideo non est inconveniens si naturalis in demonstrationibus utatur principiis mathematiciis," *In De Coelo et Mundo,* 1, 3.

[12] Dampier, W. C. D., *A History of Science,* Cambridge, 1932, C. III and IV.

and explain the world of matter. Without recourse to traditional concepts that were not believed verifiable by direct experiment, physics was able to discover laws, to explain phenomena. If God entered into the thought of the scientist, it was only that He wound up the clock of the universe and let it run. Matter and motion became the only realities worth knowing; in terms of them, the whole universe seemed explainable, from the farthest star to the smallest atom. The tide was turning not only away from philosophy but against it. As physics continued its triumphs in mechanics, in optics, in electromagnetism, in short in all fields of experiment, it tended to be viewed as the supreme science. When the physicists themselves did not feel the influences of thinkers like Kant and Hume who glorified physics, they did not at any rate advert to the insistence of orthodox thought which made physics only a part of knowledge. If the scientists did not take a positive stand against traditional philosophy, they simply ignored it as meaningless. They focused their attention on laboratory problems. It has been the neglect of all formal philosophy, much more than the acceptance of false systems, which has led gradually to the belief in physical science as the sole valid approach to the cosmos.

Newton was influenced by the English empirical tradition, which began with Francis Bacon and had been foreshadowed by his namesake and fellow countryman, Roger Bacon. But sharing in the development of classical mechanics were the continental physico-mathematicians who, if they accepted the Newtonian system, showed clearly the influence of Descartes in their important use of deduction. The divergencies in the approach to physics, from the empirical and mathematical viewpoints, remained almost geographical until very recent times. The English physicists have, as a whole, tended to emphasize the experimental method; the continentals in general have stressed the deductive use of mathematical theories. The two tributaries, however, came together eventually in physics; they also converge through Kant in the philosophy of science. Philosophy and physics have thus tended in almost parallel fashion toward the same end in shaping the contemporary attitude toward science.

Aside from their destructive work in divorcing science and philosophy, Bacon and Descartes, each in the tradition he created,

made one outstanding gift to modern science: taken together they can serve as a broad introductory definition to modern physics. Bacon contributed the method of observation and experiment. Descartes fostered the mathematization of the observed.[13] Descartes and Bacon thus complemented each other. Each is strong where the other is weak. Descartes was familiar with Bacon's works. He stated that he had nothing further to add on the subject of experiment to Bacon's work.[14] Descartes also knew and practiced induction and was, himself, an experimental scientist. It was these two general themes, that of the Baconian empirical tradition and that of Descartes, the continental mathematician, which have come together in the harmony of mathematical physics.

From the philosophical viewpoint, the two traditions enjoyed an independent development until the syncretism of Hume and Leibniz in the philosophy of Kant. Like Descartes, Kant was almost fanatically impressed with the certain character of deductive mathematical reasoning. Unlike his French forbear, he said that the *a priori* character of mathematics ruled it out as a science of the real. The result was a compromise—the synthetic *a priori* judgments, necessary in character but confined to physical experience.[15] Kant repudiated metaphysics. He enthroned physics

[13] As Descartes wrote: ". . . Mechanicae meae, hoc est Physica," *Oeuvres*, ed. Adam and Tannery, tome I, p. 524.

[14] For the relation of Bacon and Descartes, see Broad, C. D., *The Philosophy of Francis Bacon*, Cambridge, 1926, p. 64; Milhaud, G., *Descartes Savant*, Paris, 1921, pp. 213-227; Lalande, A., "Sur Quelques Textes de Bacon et Descartes," *Revue de Métaphysique et Morale*, vol. 19, pp. 296-311.

[15] "Naturwissenschaft (Physica) enthält synthetische Urteile a priori als Prinzipien in sich. Ich will nur ein Paar Sätze zum Beispeil anführen, als den Satz dass in allen Veränderungen der körperlichen Welt die Quantität der Materie unverändert bleibe, oder, dass in aller Mitteilungen der Bewegung Wirkung und Gegenwirkung jederzeit einander gleich sein müssen. An beiden ist nicht allein die Notwendigkeit mithin ihr Ursprung a priori, sondern such dass sie synthetische Sätze sind, klar. Denn in dem Begriffe der Materie denke ich mir nicht die Beharrlichkeit, sondern bloss ihre Gegenwart im Raume durch die Erfüllung desselben. Also gehe ich wirklich über den Begriff von der Materie hinaus, um etwas a priori zu ihm hinzudenken, wass ich in ihm dachte. Der Satz ist also nicht analytisch, sondern synthetisch und dennoch a priori gedacht, und so in der übrigen Sätzen des reinen Teils der Naturwissenschaft," *Immanuel Kants Werke*, Berlin, 1913, vol. 3, pp. 4-5.

as the ultimate human knowledge of the real. He sought to fix the foundations of Newtonian physics through the doctrine of the *a priori* categories.

Like Bacon, Kant had only an indirect influence on the development of physics. His influence was exerted in the nineteenth century much more through the positivism to which his attack on metaphysics gave impetus and through the general spirit of criticism which he provoked in men like Mach and Poincaré. In positivism is found the ultimate fate of the modern philosophy of science—the elevation of empirical method into the only valid means of knowing. It is this system of thought in one form or another which has permeated the outlook of the modern scientist, the modern philosopher, indeed of the modern intellectual as a whole.

It was actually with the downfall of Newtonian physics that the name of Kant has come to the fore in scientific circles. Scientists themselves have become self-critical. Though their epistemological conclusions are largely the result of independent thinking, they have a remarkable affinity to those of Kant. "We do not accept the Kantian label," Eddington writes, "but as a matter of acknowledgement, it is right to say that Kant anticipated to a remarkable extent the ideas to which we are now being impelled by the modern development of physics."[16] The ideas to which Eddington refers are simply that, even in matters of measurement, contemporary physics finds itself unable to resolve experience into rigid categories of thought. The principle of indeterminism, the failure of nineteenth-century atom "models," and the general revolt against classical physics in the quantum and relativity theories have led to the belief that the mind imposes mathematical frames upon reality after the manner of Kant's *a priori* forms. Hence, there are in reality two broad contemporary attitudes toward science, positivism and idealism, both of which have been abetted by Kant's critique of knowledge and in a more remote way by the empiricist and Cartesian traditions to which

[16] *The Philosophy of Physical Science*, Cambridge, 1939, p. 189; cf. also Haldane, J. B. S., *Possible Worlds*, London, 1927, pp. 124-9.

they owe their ultimate origins. In the last analysis, both positivism and Idealism meet the same fate. This fate is skepticism.

It must be affirmed that the current philosophy of science is not a mere classroom problem, not an accidental historical circumstance that arose suddenly and without reason. Its roots reach deep into the past. History sheds added light on its nature. The problem cannot be solved without recourse to the past. Nor can we understand even what it is and why it is important if we look only to the present. The history of philosophy of science follows a course subject to a rational interpretation which helps to understand and answer the problems raised. Above all, the historical genesis of the contemporary attitudes toward physics can indicate the complexity of the problem; it tempers the natural confidence of the *philosophia perennis* by locating its present work in proper temporal perspective.

II

The philosophical views of modern scientists and modern philosophers of science are almost invariably based upon the faith in the universal validity of scientific method. But an integral knowledge of nature cannot be so attained. If physics is incomplete because of the rejection of the real character of form and finality, an integral study of nature will be made only when these two realities are recovered. The recourse to systems of a Kantian theme will only make philosophy a type of glorified physics by elevating a part of the study of the cosmos into the whole treatment and by thus continuing in sublimated form the short-comings of Descartes and of English empiricism.

When the synthesis of the schoolmen had been supplanted by the so-called inductive sciences, it became the task of genuine philosophy, looking at the new disciplines from the outside and no longer as a part of its organic self, to evaluate the principles, methods, and conclusions of the sciences with only a general knowledge of their nature. The traditional philosophy has met this challenge in several ways; it has made distinctions: a) between the descriptive method of the physicist and the explanatory method of the philosopher; b) between mensuration and ontological interpretation; c) between induction and deduction; d) between substance, the subject-matter of philosophy, and accidents or phenomena, the subject-matter of the empirical sciences; d) between scientific facts and philosophical facts. But none of these has been entirely successful in restoring the proper order of knowledge.

Among the reasons for this lack of success are the unity of man and of matter:

First of all, man is a unified being. He does not stop to remind himself that he is now thinking as a scientist, now as a philosopher, when confronted with a given concrete problem. He is both a scientist and a philosopher in one composite. Though he may recognize in theory the distinction between the two disciplines, in practice he will ineluctably project his metaphysics as a man into the facts he observes as a scientist.[17] The inductive scientist, as the physicist is sometimes called, is today tending to become more and more deductive. Deduction and induction are, of course, interlaced in the traditional logic. Though deduction is sometimes made synonymous with the method of the syllogism, it is by induction that we come to know the principles of demonstration and the intelligible essences which form its material basis. A similar "mixed method" is in vogue among scientists. "Science is deductive as well as inductive," says Ritchie. "Induction we have always with us, but it is by itself a method of discovery only. Proof is something different."[18] Many problems are, therefore, raised by the attempt to divide science and philosophy on the basis of method. In practice, the scientist both as a scientist and as a man will not observe the distinction.[19]

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[17] "L'homme fait de la métaphysique comme il respire sans le vouloir et surtout sans s'en douter la plupart de temps," Meyerson, E., *De l'Explication dans les Sciences,* Paris, 1927, p. 20.

[18] Ritchie, A. D., *Scientific Method,* New York, 1923, p. 1.

[19] Schroedinger has well expressed the scientist's point of view in this matter: "Following Kirchoff we have been accustomed to admit that science is ultimately concerned with nothing else than a precise and conscientious description of what has been perceived through the sense. The dictum of this eminent theorist has often been quoted as a prudent warning to all those who engage in the construction of theories. From the epistemological point of view, it undoubtedly contains a good deal of truth; but it is not in accord with the psychology of research," *Science and the Human Temperament,* New York, 1935, p. 93.

The same problem is met in dividing off subject-matter. There is a distinction only between substance and accidents. There is no separation. In view of their unity in nature the scientist will naturally tend to philosophize about the substrata of the phenomena which do, after all, introduce us to an indirect cognition of substance.[20] Hence, the distinction between science and philosophy is again not rigidly observed in practice. Duhem was right in pointing out that there is more certitude in the popular mind than in science *qua* science since there is a deeper ontology in the former case than in the study of mutable contingent accidents alone.[21] Empirical knowledge in its pure form is not humanly practical. The scientist is not only a scientist. He is a man. The human mind will ask and answer in some way questions concerning the ultimate nature of the material world.

This does not mean that it has been false and fruitless to make these distinctions. They do exist. They must be recognized in a speculative sense. In a practical way they have done much to clear up the confusion and conflict prevailing between science and philosophy since they parted ways at the close of the middle ages. It will be found necessary to make such distinctions in the following pages. But a complete peace will not be re-established on a practical plane until the two branches are reunited in organic harmony on the common tree of knowledge. The philosopher can do his share by approaching the scientist, and speaking his language, lead the discussion to a plane where all discussions, in the natural order, end—philosophy. Meanwhile, awaiting the reintegration of science and philosophy, western thought must make the best of a house divided against itself.

The fundamental difference between empirical and philosophical science is that the former attempts to measure phenomena while the latter proposes to examine the nature of these phenomena and their ultimate foundations. But the problem cannot be so summarily dismissed. The scientist certainly represents the object that he measures. Otherwise he should not know that it was there to measure or what type of measurement to apply—the scientist studies *something*.[22] The scientist first seeks to determine the invariant properties of the cosmos. He is only secondly concerned with the question: how much?[23] The question then arises as to the conceptual basis of science as an idea of structure and the ontal significance of this representation.

[20] "In rebus enim sensibilibus ipsae differentiae essentiales nobis ignotae sunt; unde significantur per differentias accidentales quae ex essentialibus oriuntur," *de Ente et Essentia*, c. 5. Scientists of course do not refer to the concept of substance in their own method, but the point is that from reality's manifestations they tend to philosophize about ultimate things.

[21] Duhem, P., *La Théorie Physique*, Paris, 1914, pp. 402-3.

In a general sense, science tends to study matter by breaking it up. Philosophy, employing an analytico-synthetic method with synthesis playing the major role, tries to account for the union of the component parts into a substantial whole and for the ultimate intrinsic and extrinsic causes of the material universe. As Herzfeld notes, "one should say that it is the deliberate experiment which is characteristic of modern science. That means philosophically that while the Middle Ages had a preference for the 'natural state,' we think that we must first simplify the complicated conditions which occur in nature and break them down into more fundamental parts."[24] Despite the fashion of modern physics to reject the mechanical account of matter, its method is still mechanical in the broad sense of that word,[25] as we shall later see. The statement made by Lord Kelvin could still be attributed with a proper exegesis to modern physics: "I never satisfy myself until I can make a mechanical model of a thing." Physics tends to understand matter by breaking it up. In this, it is obedient to the guiding philosophical spirits of modern empirical science. Bacon advocated "a very diligent anatomy and dissection of the world,"[26] and his atomistic doctrine of forms shows more clearly

[22] Salmon, E. G., "Philosophy and Science," *The New Scholasticism*, 16, 1942, p. 146.

[23] Levy, H., *The Universe of Science*, London, 1932, p. 188.

[24] "The Frontiers of Modern Physics and Philosophy," *Proc. Amer. Cath. Phil. Assoc.*, 1930, p. 39.

[25] By mechanism is meant the tendency to treat being as the mere sum of its component quantities. Modern physics has challenged the accuracy of *measuring* these parts, but the fundamental concept of a material being for the physicist is still purely *partitive*.

[26] *Op. cit.*, vol. 4, p. 110.

what he means. If quantity were the essence of body, as Descartes held, then matter should be studied by dividing the quantity into parts exactly as we treat number in mathematical equations. Bodies are considered not as wholes but as sums. In its attitude toward structure, physics tends to reduce its subject-matter to terms of quantity.

The empirical sciences may be divided into two groups: the physical and the biological. The physical may again be subdivided into physics and chemistry, although "the difference between the two is fast becoming microscopic."[27] Chemistry tends to reduce its treatment of matter to the electrons of the atom which account for the chemical properties. Modern physics, on the other hand, has shifted its center of gravity from the macroscopic to the atomic world, and atomic physics is centering its attention on nuclear phenomena where most of the physical properties originate. Since the electronic phenomena of an atom depend ultimately on the number of nuclear protons, chemistry looks to atomic physics for a final answer to chemical structure. Biology follows a similar path. It studies a living thing as a physico-chemical system. Its account of structure must share the fate of the chemical and physical ones it presupposes by being reduced ultimately to the partitive phenomena studied by atomic physics. This mechanical approach to the study of life is a necessity of the experimental method, as Needham points out; it may not represent the philosophical analysis of the scientist *qua* man.[28] If experimental biology did not seek after a physico-chemical account of vital phenomena, it would surrender its title as an empirical science. This philosophy of method is of fundamental importance in the solution of conflicts between science and philosophy. It may be expanded, as Needham indicates, to all of the physical sciences. "Mechanism," he writes, "cannot possibly be abandoned, for it was evidently contained potentially in the scientific method itself."[29] To measure and correlate the quantified aspects of being, the empirical scientist must by the very nature of his method confine his study to the quantified aspects of things, reducing all bodies, living or lifeless, to mechanical parts and their mechanical interactions.

[27] Lindsay, R. B., "The Impact of Science on Contemporary Civilization," Brown University series, "Science and the Citizen," reprinted in the *Sigma Xi Quarterly*, Jan., 1942, p. 58.

[28] "We now possess a conception of the mechanistic theory of life as a method, the method of scientific exploration, and only methodologically representing truth. Moreover, this method can be applied to no matter what. Things that do not fit into its metrical scheme can certainly not be treated scientifically, but may be none the less valid for all that: what is impertinent in Physic may yet well be inquired in Metaphysic. In the past, of course, the mechanistic theory of life has nearly always been treated as a philosophy and not as a methodological fiction," Needham, J., *The Sceptical Biologist*, London, 1929, p. 27.

As Needham indicates, the "logical" materialism of scientific method has nothing to do with metaphysical materialism,[30] nor, one may add to be more specific, has it anything to do with metaphysical atomism. Bergson recognized that positive science must assume organization to be like making a machine; it is only on this assumption that it can gain a hold on reality.[31] Whitehead has argued that "the whole concept of materialism only applies to very abstract entities, the products of logical discernment."[32] By its very nature, "methodological mechanism" applies only to that portion of the world which is amenable to its treatment. But the danger of the mechanical approach lies in the fact that it may be elevated from a methodological necessity into a philosophical dogma and extended beyond the domain where it applies. It is strictly a technique of physical science. As such, it still leaves room for a study of the world by the method of philosophy.[33]

Since, then, both chemistry and biology resolve themselves, in their last analysis of structure, to atomic physics, we can, by a

[29] *Ibid.*, p. 18; cf. also p. 84. Also: "Now scientific method, we repeat, is and must needs be mechanistic," Joad, C. E. M., *Philosophical Aspects of Modern Science*, London, 1932, p. 201.

[30] *Op. cit.*, pp. 119-20.

[31] Bergson, H., *L'Evolution Créatrice*, Paris, 1910, p. 101.

[32] Whitehead, A. N., *Science and the Modern World*, p. 111; cf. also by the same author, *Principles of Natural Knowledge*, Cambridge, 1919, p. 91.

[33] However, the traditional philosopher will not accede to Needham's thesis that the mechanical and telic accounts of reality are united by a mystical intuition. The unifying principle is that unity which is being itself and which is attained in knowledge not by mysticism but by intuition.

study of the latter branch, arrive at the ultimate analysis of matter possible within the methodological mechanism of modern science and arrive also at the meaning of this account in the light of philosophy.

III

Physics, like the other empirical sciences, attempts to measure the quantified data of the material world in order to obtain a general knowledge of their interrelationships and thus to predict future phenomena. This definition involves three important steps that represent the method of physics: 1) mensuration of quantified data: 2) general knowledge of the interrelationships of the mensurable data (theory); and 3) the prediction of new phenomena (verification).

But the method of physics begins by jumping, so to say, *in medias res*. The physicist does not approach his subject-matter with a completely passive mind. He makes presuppositions. Upon their validity, the whole structure of his science must stand or fall. These suppositions are not made in a conscious, deliberate way. They are commonplace truths to all men. They permeate so naturally and unobtrusively the procedure of the scientist, as indeed the whole life of thinking men, that they do not seem to be presuppositions. In actual practice they are not questioned. Examination of these presuppositions lies beyond the ambit of scientific method. They are postulates from epistemology, logic, metaphysics, and the philosophy of mathematics.

From epistemology the physicist accepts the existence of the external world, the validity of sense and intellectual knowledge, and the first principles of thought and being—the principles of identity, of non-contradiction, and of the excluded middle.[34]

From logic the scientist must assume the validity of discursive reasoning, the operation by which the mind passes from the rela-

[34] A denial of any of these three facts and principles can only lead to skepticism, idealism, and the death of science. As Planck remarks: "A science that starts off by predicting the denial of objectivity has already passed sentence on itself. Of what value to the world are the sensory impressions of a mere individual?" *Where is Science Going*, New York, 1932, p. 81.

tions of premises to the conclusion which such relations impose. Such reasoning is not arbitrary. It is governed by law. These laws must be sought out and proved. The view of the scientist on the nature of his science is also a postulate from logic. What is the unifying element in the science? What is its object? What is its method? Though Planck admits the need of a philosophical complement to physics, he seems to think that the physicist himself is best qualified to pass on the merits of his method.[35] But if the physicist examines his own method, he is doing so only by abandoning his empirical discipline and entering upon a field where he is no longer a physicist but a philosopher. On the other hand, if the physicist employs the empirical method to examine the empirical method, he takes the path of the infinite regress, circular demonstration.[36] The use of the philosophical method is in the legitimate scope of philosophy, just as the use of experiment belongs to the world of experimental science. Schroedinger, like Planck one of the foremost of modern physicists, recognizes the place of philosophy in examining the methods of science. He rightly insists, however, that philosophers must acquaint themselves with what the physicist does before passing judgment on its value.[37] This counsel is of great importance in present subatomic research. Probability in physics, to take only one example, is an empirico-mathematical concept that is not in conflict with either Aristotelian logic or the traditional cosmology; it simply operates on a different noematic level. But if the philosopher is to fulfill his mission as a critic of the method of science, he must acquaint himself with the way in which physicists solve such problems as those involving probability-amplitudes and statistical mechanics. Probability and statistics—terms widely used in the extremely technical domain of contemporary quantum theory—are in the last analysis dependent on philosophical interpretation. Otherwise their inner mathematical conclusions will invade—as they have so forcefully done in the minds of Eddington, Jeans, Pauli, Heisenberg,

[35] *Wege zur Physikalische Erkenntnis*, Leipzig, 1934, p. 177.

[36] The philosopher points out the escape from this circle which is the self-evident character of truths, so simple that they need no proof and so far-reaching that they are pre-supposed by any attempt to prove them.

[37] *Op. cit.*, p. 51.

and others—the region of philosophy itself. If philosophy studies the method of science, then there can no more be opposition between true science and true philosophy than between nature and true science.[38]

From metaphysics, empirical science postulates the principle of causality, the existence of plurality marked by identity, diversity, and permanence,[39] and above all the uniformity of nature. Elaborating on the concept of the uniformity of nature, Bridgman adds that science must presuppose the simplicity of nature, its finiteness, the determinateness of the future in terms of the present.[40] Even in the new quantum mechanics where the accurate prediction of the future from the past, according to the Laplacian ideal, is no longer possible, there is a form of prediction (in psi-functions), very accurate indeed, where the fate of a mass of particles is known, even if this or that individual cannot be mathematically described. "Probability amplitudes," as will be shown, represent order, a determinateness. In a disordered world, science would be impossible.

From the philosophy of mathematics, the scientist must be acquainted with the nature and scope of mathematics and its relation to the real world. Are the complex number and mathematical infinity real beings? Is non-Euclidian geometry a being of the reason? These, Maritain points out, are samples of questions in the philosophy of mathematics which the physicist must either treat philosophically for himself or pre-suppose as answered by the specialist in philosophy.[41] There are other questions in the philosophy of mathematics which the physicist must postulate for his empirical study, including of course the fundamental guarantee of a mathematical equation as found in ontology and theodicy.[42]

[38] Benjamin, A., *An Introduction to the Philosophy of Science,* New York, 1937, p. 22.

[39] Becher, E., *Philosophische Voraussetzungen der exakten Naturwissenschaften,* Leipzig, 1907, p. 112.

[40] Bridgman, *The Logic of Modern Physics,* New York, 1927, pp. 197 ff.

[41] *Les Degrés du Savoir,* Paris, 1932, p. 100.

[42] What Laplace may have meant by his supposed remark to Napoleon that in his *Mécanique Céléste* he had no need for the "hypothesis" of God, we find it necessary to return to God if we are to guarantee our certitude;

Such are some of the presuppositions of physics. If the scientist is not to proceed on blind faith as Dotterer seems to suggest,[43] if he is to have a rationally justified method just as he seeks rational justification for every step in the actual employment of his method, then the presuppositions must be examined by the non-empirical science which is philosophy. We find therefore that physics is incomplete at the outset. It must postulate principles from philosophy before the scientific method, properly speaking, can begin work. Otherwise, it would be beginning in an arbitrary way and would be risking its whole superstructure on assumptions made at the outset, without their submission to the rational examination of philosophy. No conclusion is stronger than its premises.

Once these postulates are established, the physicist can deploy his method of measurement, correlation, and prediction mentioned above. This division of the scientist's activity may be another of those over-simplifying generalizations about scientific method unless it is properly interpreted. Besides finding subdivisions in the three steps, their frequent overlapping, and shifts in the order of their application,[44] one may discover the persistent obtrusion of the scientist's intellectual activity, as a man, through his technical procedure as a scientist.

Measurement, for example, involves much more than the mere act of observing coincidences between calibrated scales and the activity of matter. The scientist must first of all select his data. For though in a certain sense, physics proceeds by a trial-and-error method, yet the range of questions is limited by the scientist's foreknowledge, based on experience and on an intellectual analysis of a given problem, of the type and magnitude of the measured answers that are likely. Millikan knew, for example, when he measured the charge on the electron that he should use a voltmeter, and not a stethoscope, to record the force necessary to raise his oil-droplets against the force of gravitation. Theory is inter-

for nothing can ever be true unless there be truth. No act of composing and dividing, be it a judgment or an equation, can ever be true unless there is a being simply and subsistently true.

[43] *Philosophy by Way of the Sciences,* New York, 1929, p. 124.

[44] Naville, E., *La Logique de l'Hypothèse,* Paris, 1895, p. 68.

woven with experiment. But the two are certainly not the same in their precise senses. So bearing in mind that they often go hand in hand, we are justified in distinguishing their respective roles for purposes of study.

Nor is the contemporary attitude toward experiment without its past parallels. Experiment was described by Aquinas, developing Aristotle's thought on the subject, in a very striking way. It owes its origin, he says, to the remembrance that certain facts have been noted time and again in connection with a given thing. It proceeds as a type of reasoning concerning particulars. Thus, Aquinas goes on, when a doctor has observed that a certain herb has cured many individuals of fever, he accepts as a principle of his art and science that this herb is a cure for fever.[45] The doctor undoubtedly tried other medicines before he hit upon the right one. When he discovered that the herb was successful in one case, he prescribed it for others before arriving at a general principle. This description is echoed in the words of Eddington who points out, though with a savor of subjectivism, that scientific knowledge arises from the association of certain memories of past experience.[46] What Aquinas thought on the subject of experiment is in remarkable harmony with the method of modern science. Lindsay and Margenau, discussing experiment from the point of view of contemporary physics, declare that experiment involves: "(1) the abstraction from the totality of experience of a small domain for special investigation; (2) the presence in the mind of the experimenter of ideas relating to this domain leading him to frame certain questions the answers to which he seeks; (3) the operational character of the experiment involving well-defined activity on the part of the experimenter."[47]

The first point in the foregoing definition cannot be italicized too much in view of the significance it has for a correct understanding that the field of scientific inquiry and the method of scientific procedure do not embrace the totality of being and of knowledge. Forward-looking physicists are quick to admit that

[45] *In II An. Post.* 20.
[46] *The Philosophy of Physical Science*, p. 189.
[47] *The Foundations of Physics*, New York, 1936, p. 5.

they are dealing with only a small part of the real world in their experiments. Eddington, impressed with the circumscribed nature of modern physics, speaks of "selective subjectivism" by which we limit the field of physical inquiry and then limit our method of studying the field itself.[48] As it has often been put, modern physics with its specialized branches and specialized techniques tends to learn more and more about less and less. The whole point is of capital value for a critique of the sciences. It is evident that if physics studies only a small portion of the real world, there is need for a science of the totality which is philosophy.

The experimenter, Lindsay and Margenau continue, has certain preconceived questions. As Aquinas says, in experiment there is a remembrance of past impressions. Philosophy, as Plato and Aristotle noted, begins in wonder. This is also true of the empirical sciences in their knowledge character. But man has more than a vague curiosity. He wants to know particular causal conditions. Experiment becomes "nature's answer to man's questions."[49] In a wider sense, however, nature is only the means by which man answers his own questions. Much of our data in atomic physics, for instance, are derived from spectroscopy. The spectra of the various elements are, for example, correlative with their positions in the periodic table; they have even predicted elements discovered later. But these are not only conclusions from the data themselves. They are nature's language decoded by the physicist. In this light, Duhem was right in insisting on the role of interpretation in experiment.[50] Not only does man answer his scientific questions by interpreting an experiment performed on nature. He has an idea beforehand of what the answer is likely to be. This anticipation of nature is aided by hypothesis.[51]

Finally, Lindsay and Margenau call attention to the operational character of the experiment. This operational aspect arises from

[48] *Op. cit.* (*passim*).
[49] Dingler, H., *Das Experiment*, Munich, 1938, pp. 39-40.
[50] *Op. cit.*, pp. 111 ff.
[51] "Normally, an experiment is performed for the sake of verifying an hypothesis; hence, there is a definite control of the set-up and an anticipation of the outcome." Benjamin, *The Logical Structure of Science*, New York, 1936, p. 271.

our attempt to measure phenomena. It imposes obvious limitations on the scientist to remain strictly within empirical bounds according to his own canons of verification. Operations, when they are of the physical type, are also of capital importance in view of what Herzfeld has called "the deliberate experiment which is characteristic of modern science."[52] Aside from the problem of eliminating such extraneous forces as gravitation and electrostatic action where their effect is not directly pertinent to the outcome of an experiment, there is a persistent source of error arising from the interference of measuring instruments with the subject of study. This fact is embodied in the Heisenberg principle of indeterminism which states that it is impossible to measure the position and momentum of a particle simultaneously and that therefore the question of the simultaneous location and velocity of a particle has no meaning in physics.

All experiments involve isolation of elements from the complexus of reality. An experiment is a controlled sense-perception which simplifies the variables of a problem. But we can never boast of the complete isolation of our subject-matter. We cannot extract a single phenomenon from nature, eliminating all outside influences. In our operations, we may by a suitable apparatus cut down the effect of interfering factors to a negligible point, or we may correct for the interference by mathematical means. But there is no strictly isolated system except the whole universe.[53]

Finally, an experiment must be repeatable according to the demands of universality and objectivity which are the pre-requisites for any science, philosophical or empirical. In a practical way, this repetition is fraught with serious problems.[54] Though two experiments may be sufficiently alike to be practically identical, we may nevertheless remember their differences in our employment of the phrase "exact science." It was not necessary for

[52] Cf. *supra*, p. 8.

[53] Levy, H., *op. cit.*, p. 52.

[54] "Unfortunately, we cannot repeat an experiment under exactly the same conditions. The time of the day, the season of the year, the past history of the bodies operated on are subject to incessant change. No two experiments can truthfully be said to occur under exactly the same conditions," d'Abro, A., *The Decline of Mechanism*, New York, 1939, p. 17.

Aquinas, in his discussion of experiment, to lay stress on the problems arising from the operational character of the example he used. He was not dealing with reality from the point of view of measurement. This approach to reality, as Bergson has pointed out, is the distinguishing feature of modern empirical science.[55]

The foregoing pages have presented an historical summary of the attitude toward physics since it emerged from the traditional synthesis of knowledge. In the discussion which followed, the general characteristics of the so-called scientific method, its postulates and its central theme, experiment, were sketched. This introductory definition of the empirical method has already led us to important frontiers. The logical procedure of physics may now be examined in more detailed form.

[55] *Evolution Créatrice*, p. 360.

CHAPTER II

Measurement in Physics

The purpose of empirical inquiry is to discover and measure the relationships of phenomena. The physicist is not concerned with the beauty of the rosy-fingered dawn that attracted Homer or with the "plaintive anthem" of the nightingale that enraptured Keats. He is interested in the refraction of the light and in the amplitude and frequency of the sound. He is concerned with measurement.

Measurement may be treated, for the sake of convenience, under six headings: 1) the description of measurement; 2) the limits of measurement in its object; 3) the limits of measurement in its method; 4) statistics as a substitute for exact measurement; 5) the results of measurement—equations; and 6) scientific law.

Measurement is the process of correlating numbers with things that are not numbered.[1] It consists first in the assignment of suitable units to material, quantified phenomena, and, secondly, in the computation, by proper mathematical operations on these units, of related magnitudes.

All instruments involve the registering of results, however heterogeneous they may be in their ontal status, by geometrical means. Whether we employ an ordinary yardstick, a thermometer, an analytical balance, a spectrum, or a Geiger counter which measures radioactive decay by means of an electrometer, the readings involve the spatial coincidence of a point or line with a mark on a calibrated scale. Even such a magnitude as the velocity of light was computed by Michelson from the comparison, with time, of the reflections of a beam of light falling on a rotating mirror. Both the angular rotation of the mirror and the time were measured geometrically.[2]

[1] Cf. Nagel, E., *On the Logic of Measurement*, New York, 1930, p. 37.
[2] Ritchie, A. D., *op. cit.*, p. 125.

Eddington writes: "Whether we are studying a material object, a magnetic field, a geometrical figure, or a duration of time, our scientific information is summed up in measures; neither the apparatus of measurement nor the mode of using it suggests that there is anything essentially different in these problems."[3] Hence, Eddington reduces physics to a science of pointer-readings.

But we cannot accept Eddington's generalization. To say that physics is only a science of pointer-readings[4] is another of those over-simplifying solutions of the relation of science and philosophy that have only complicated the real problem. Measurement involves a theory of what takes place in the measuring instrument.[5] How can we correlate geometry with electrostatics, radioactivity, temperature, pressure, and the like—unless we have, by insight and reasoning, reached a knowledge of the interrelation of the readable results on a graduated scale and the phenomenon we measure?[6] There is something more than pointer-readings.

Heisenberg has rightly pointed out that in contemporary atomic physics instruments and theories are mutually dependent.[7] In building our apparatus, a theory of the measured object is presupposed. This is illustrated in the complex atom-smashing machines now in use, the Van der Graff generator and the cyclotron. It was only with the advance of atomic and electrical theory that such instruments became possible. To take another example, Aston devised a way of measuring the masses of various isotypes by observing the deviations of the positive ions of elements in electric and magnetic fields. But the method involved many theoretical considerations besides the mere observation of recording photographs, the analogues, in these experiments, of Eddington's pointer-readings. Anderson's discovery of the positron would

[3] *The Nature of the Physical World*, Cambridge, 1933.
[4] *Ibid.*, pp. 251 ff.
[5] Planck, M., *Where Is Science Going?* p. 97.
[6] ". . . no amount of description of things can tell us what anything is for. There is nothing in any law of Physics to tell us that a clock is for keeping time. The laws of nature tell us that the hands go around at a particular uniform speed and that is all," Ritchie, A. D., *op. cit.*, p. 182.
[7] *Wandlungen in den Grundlagen der Naturwissenschaft*, Leipzig, 1936, pp. 16-18.

never have been possible if he had not had the insight to interpret in terms of something non-geometrical the geometrical paths of particles shown on a photograph.[8] Eventually, measurement involves a judgment about the qualitative world where all our knowledge begins.

To speak of physics as a science of pointer-readings is a confusing definition that puts the physicist in the same class with the motorist reading his speedometer and the railroad engineer watching his pressure-gauge. Mensuration is only the formal object of physics, the point of view taken on the subject-matter. The subject-matter, or the material object, is the corporeal world. As Maritain has insisted, contemporary physics is a type of *scientia media,* formally mathematical and materially physical, which was described by Aristotle, Aquinas, and Cajetan.[9] Physics studies the material world in its mensurable aspects. Experiments on matter, interpreted by physical insight, form a legitimate and necessary means of realizing the fullness of the formal object of physics, mensuration. Mensuration is enriched and multiplied in this way.

[8] Planck has summed up the case thus: "Eine Methode physikalischer Messung aber, bei der jewede auf Induktion beruhende Erkenntnis ausgeschaltet ist, existiert überhaupt nicht; das gilt auch für die direkte Wägung. Ein einziger Blick in ein Präzisionslaboratorium zeigt uns die Summe von Erfahrungen und Abstraktionen, welche gerade in einer solchen scheinbar so einfachen Messung enthalten ist," *Wege zur Physikalischen Erkenntnis,* p. 29.

[9] Maritain, J., *op. cit.,* pp. 83-84; cf. also by the same author, "The Conflict of Methods at the Close of the Middle Ages," *The Thomist,* 3, 1941, p. 530. St. Thomas writes: "Quilibet cognoscitivus formaliter quidem respicit medium per quod aliquid cognoscitur; materialiter autem id, quod per medium cognoscitur; et quia id quod est formale, potius est, ideo illae scientiae quae ex principiis mathematicis concludunt circa materiam naturalem, magis cum mathematicis connumerantur, utpote eis similiores, licet quantum ad materiam magis conveniant cum naturali; et propter hoc dicitur in II Physic. quod sunt magis naturales." II-II, 9, 2 ad 3. Commenting on this passage, Cajetan adds: "Non dicitur quod scientiae mediae sunt magis mathematicae quam naturales; cum falsum sit absolute loquendo; quia simpliciter sunt scientiae naturales, utpote non abstrahentes a materia sensibili. Omnis enim scientia non abstrahens a materia sensibili est naturalis, ut patet VI Metaph. Sed dicitur quod connumerantur magis cum mathematicis, utpote eis similiores."

But physics is not only pointer-readings. It is precisely because he neglects the material object, *that which* is studied, and defines physics only from the viewpoint of its formal object that Eddington reaches his extreme view. So also Jeans, if we have interpreted his thought correctly, seems to place the essence of reality in mathematics.[10]

Bergson, with another end in view, insists on the symbolic character of physics. Though we may disagree with his philosophy of *la durée pure,* he nevertheless pointed out very forcefully against the positivism of his time that physics represents the world only in terms of mathematical symbols and thus is asymptotic to the essence of the real. Time in physics, he argued, is measured by the trajectory of a moving point *t.* For the scientist, time is a line in space.[11] Time for the physicist is therefore spatialized. The same criticism applies to movement in general. Physical science tends to reduce motion to the immobility of positions on mathematical lines.[12] Bergson admitted the existence of a real world. What he denied was that physics discussed its real nature.

Bergson applied his searching criticism also to the four-dimentional space-time continuum proposed by Minkowski and incorporated into the theory of relativity. This idea has caused so much misunderstanding because by it space and time, for modern thought, became confused with their symbolic representation.[13] Pointing out that the four-dimensional continuum is only a sym-

[10] ". . . the final truth about a phenomenon resides in the mathematical description of it. . . ." *The Mysterious Universe,* New York, 1937, p. 176; also: ". . . the universe can be best pictured, although still very imperfectly and inadequately, as consisting of pure thought, the thought of what, for want of a better word, we must describe as a mathematical thinker," *ibid.,* p. 160.

[11] *La Pensée et le Mouvant,* Paris, 1939, p. 9.

[12] *La Durée et Simultanéité,* Paris, 1923, p. 69.

[13] Eddington, for instance, in spite of his insistence that physics is purely metrical and a record of pointer-readings, starts out his most famous work, *The Nature of the Physical World,* with the misleading statement: "Between 1905 and 1908, Einstein and Minkowski introduced fundamental changes in our ideas of space and time." This is a false or at most equivocal statement. Relativity did not introduce changes in the ideas of space and time but only in our measurement of the two realities.

bolic expression, Bergson declares that it says nothing "new about space and time: these remain what they were, distinct from one another, incapable of being united except by means of a mathematical fiction, intended to symbolize a physical truth."[14] Though he erred in his idea of the nature of ultimate material reality, Bergson admitted its existence. His criticism of positive science as a merely symbolic study of the metrical aspects of this ontal world will remain as one of the weighty contributions of his genius to France and to philosophy. The real world forms the subject-matter of physics; the symbols are merely involved in its point of view.

From one aspect, measurement seems to involve a vicious circle. Classical mechanics, for instance, is reducible to Newton's three laws.[15] Is it a mere pleonasm to say that force equals mass times acceleration? D'Alembert, Lagrange, Hamilton, and others attempted to lay the basis for mechanics in various other ways. D'Alembert, for instance, reasoning from an equation of equilibrium, set up a formula in which actual motion was defined as the resultant of impressed motion and of the constraint of factors which did not leave the impressed particle free to act. At first sight this seems to be tautology. But it is merely a definition of an elementary standard of measurement that permeates all succeeding operations. This condition is as it should be. Mechanics is formally a mathematical science. Unless we are to fall victim to an infinite regress, we must come to a point where definition

[14] *Op. cit.*, p. 234. The word "fiction," however, will be qualified when we come to discuss the relation of theories to reality. Here it need only be noted that since Relativity tensor equations only measure reality, they are silent about matter's ontic structure.

[15] Newton's first law of motion states that every body continues in its state of rest or uniform motion, except in so far as it is compelled by forces to change that state. Eddington argues that since force defines motion and motion, force in Newton's concept, the first law means: "Every body continues in a state of rest or uniform motion in a straight line, except in so far as it doesn't," *op. cit.*, p. 124. Newton did not, however, mean to define force in this way. He assumed that the idea of force was known to common sense from the physiological reactions experienced in a push or pull. It is the aim of contemporary physics to eliminate these so-called "anthropomorphic" elements.

replaces demonstration as a source of knowledge.[16] Definition is not nonsense but based on direct evidence as opposed to the indirection of demonstration.

In this connection, Eddington has argued that all physical concepts are interlocked in a "cyclic method" of definition. "Electric force," he writes, "is defined as something which causes the motion of an electric charge; an electric charge is something which exerts electric force. So that an electric charge is something that exerts something that produces motion of something that exerts something that produces . . . ad infinitum."[17] A circular definition is neither intelligible nor useful. It merely repeats the concept to be defined, and the problem of definition remains.

But Eddington's view is grounded on a misconception. Physics does not proceed from circular definitions. To define is basically a process of apprehension or mental analysis. In such an operation, it may be agreed with Riezler that the "relation (child-father) is prior to the relata. You do not define one by means of the other but each by means of a whole that is articulated within itself."[18] The whole is grasped by abstraction. Force and charge, like the motive and restraining forces in d'Alembert's equation, are defined in terms of the totality which the mind apprehends. Hence there is no vicious circle. There is a meaningful definition. Eddington's difficulty seems to spring from the belief that the mathematical alone is meaningful. This is a gross misconception. Even in physics, mathematical reasoning must be preceded, accompanied, and followed by intellectual insight into realities and relations that give meaning to the mathematics. Though physics may define its material in terms of mathematical functionality and not of essential

[16] This bears witness to the fact that science is not completely inductive, induction being a type of argument. Nor is philosophy wholly deductive and syllogistic. The idea of being is attained not by demonstration but by direct insight. Without reference to this idea, neither philosophy nor physics is intelligible.

[17] *Op. cit.*, p. 264.

[18] Riezler, K., *Physics and Reality*, New Haven, 1940, p. 102. This whole problem is provoked by the demand of the Positivist spirit that even the obvious, which can be grasped by direct, immediate apprehension, be made a matter of demonstration.

relations, the same *logical* operation is involved as when, for instance, we define man. It is the same, from the point of view of *formal* logic, to recognize that man is a rational animal as to recognize that $y = f(x)$.

Measurement was defined as a type of correlation between numbers and the non-numbered. The correlation is the most important fact. Numbers assigned to the various quantities may differ according to the scale employed—whether, for instance, it be the English or metric system, centigrade, Fahrenheit, or absolute temperature, the micron or the Angstrom unit. The fundamental element is not the numbers but the ratio between them which is the same in whatever measuring system we employ.[19] Ratios can be conveniently expressed in terms of functionality and resolved into the form of differential equations. One quantity is said to be a function of another if, when the second takes on a value, the first takes on a corresponding value. Functions may be combined in parametric form; they may be expressed in terms of other variables. But there is still the same method of evaluation, the same interrelationship, so that when one function (or one variable) is assigned a value, the other functions (or other variables) take on corresponding values. Functionality, embodied in differential equations, is the usual form of expressing the results of measurement in physics.

Nature does not measure, does not count, Bergson wrote.[20] But if our meter-sticks and stop-clocks are standards relative to man, present-day physics believes to have found a way of measuring the *absolute* space-time relationships in the theory of relativity.

The theory has its origin in the Michelson-Morley attempt to measure the ether-drift, an experiment which proved that the velocity of light is constant: that, for instance, whether the earth is moving toward the sun or away from it, the relative velocity of the light is the same.[21] The Lorentz-Fitzgerald contraction theory

[19] Bridgman, P. W., *Dimensional Analysis,* New Haven, 1936, p. 13; cf. also Campbell, N. R., *Measurement and Calculation,* London, 1938 (*passim*).

[20] *L'Evolution Créatrice,* p. 239.

[21] This is not what we should expect according to the ordinary laws of the composition and resolution of velocity. If A is moving forward five miles an hour in a train that is moving in the same direction thirty miles per hour, he would be travelling forward at the rate of thirty-five miles per hour. If B is on a train travelling thirty miles an hour and if he is walking against the direction of the train with a velocity of five miles per hour, he would be moving forward at a rate of twenty-five miles per hour. The significance of the Michelson-Morley experiment, then, is this: if A and B represent the light and the earth is the train, the velocity of A and B is exactly the same in both cases.

attempted to account for this deviation from known laws of composition and resolution of velocities; it supposed that a body moving through the ether contracted in a direction parallel to its movement by an amount sufficient to account for the results of the Michelson-Morley experiment.[22] Lorentz also set up a series of equations to transform co-ordinates from one frame of reference to another, according to the contraction theory.[23]

Then, in 1906, Einstein announced his special or restricted theory of relativity. Prescinding from the question of the existence of an ether, he made two far-reaching assumptions concerning uniform translatory motion: a) that there is no unique or privileged co-ordinate system but that any observer in relative motion may consider himself at rest and use this frame of reference in his observations; and b) that the velocity of light is independent of the motion of the observer.[24] Einstein's statement of the relativity of motion makes it permissible to say interchangeably that the moving body A is in motion relative to B or that B is moving relative to A. His arguments on time sum up to the conclusion that there is no absolute simultaneity but only simultaneity relative to a given frame of reference. Without accepting the contraction

[22] Writing of the Lorentz-Fitzgerald contraction theory, Einstein says: "But on the basis of the theory of relativity the method of interpretation is incomparably more satisfactory. According to this theory, there is no such thing as a 'specially favored' (unique) co-ordinate system to occasion the introduction of the aether-idea, and hence there can be no aether drift, nor any experiment with which to demonstrate it," *Relativity,* New York, 1931, p. 63.

[23] Lorentz, H. A., "Electro-magnetic Phenomena in a System Moving With Any Velocity Less than that of Light," in Lorentz, Einstein, Minkowski, Weyl, *The Principle of Relativity* (A Collection of Original Memoirs on the Special and General Theory of Relativity), London, 1923, pp. 11-34.

[24] Einstein, A., "On the Electrodynamics of Moving Bodies," *ibid.,* pp. 37-55.

theory, Einstein was nevertheless able to incorporate the Lorentz transformation into his theory to account for changes from one frame of reference to another.[25] The theory of relativity, as Langevin and Sullivan have stated, is in reality a theory of absolutes since it discovers invariants in the changes from one inertial system to another.[26]

The general theory of relativity—generalized to include bodies in rotational motion and therefore containing the restricted theory as a special case—is an attempt to grasp the universal, fundamental metrical relations of the material world. It introduces a new concept of field and aims to combine gravitational and electromagnetic phenomena in one relation. But in the theory of relativity, gravitation and electromagnetism are clothed in new form. They are not properties of bodies. The Newtonian concept of gravitation can be considered as the equivalent of a properly accelerated system in space. Newton's law, according to relativistic principles, views the world in terms of Euclidian geometry, it therefore holds only in ordinary, apparently Euclidian space. If on the other hand we construct a geometry based on the Gaussian arc elements—in which space is regarded as curved—the laws of motion can be derived in universal form without reference to gravitational forces. The mathematical technique is that of the tensor calculus which, it is said, enables relativity mechanics to read down to the fundamental properties of matter.[27] Just as there is no absolute motion, so there is no absolute acceleration. But the invariants in changing from one frame of reference to another can be computed from the tensor calculus. The general theory of relativity purports to combine gravitational and electromagnetic properties of the material universe as properties of space and to interpret these in terms of geometry.[28] But the general theory of relativity, as Bergson said, is, like all other physico-mathematical systems, a symbolic representation of the metrical aspects of matter. It is

[25] *Relativity*, p. 51.
[26] Born, M., *Einstein's Theory of Relativity*, London, 1924, p. 246.
[27] Nagel, E., *op. cit.*, p. 71.
[28] Einstein, A., *The Meaning of Relativity*," London, 1932, p. 62.

not an ontology of nature.[29] It is a system of measurement. Mathematics only touches the quantity in matter. The physical aspects of the theory of relativity only simplify and suggest measurements. The essence of matter is in another order.

It may be added, just to complete the relation of Einstein's theory to measurement, that relativistic corrections demanded by the restricted theory need only apply where velocities are very high. The general theory, which formulates the Newtonian concept of gravitation in more universal form, also agrees very closely with Newtonian mechanics in ordinary space. Its value as a theory lies in the fact that it covers phenomena in interstellar spaces where Newtonian mechanics does not hold; it therefore includes Newtonian mechanics as a special case by restricting its field of application. But relativity, though it need not be applied where its corrections would be negligible, is nevertheless theoretically involved in every process of mensuration in modern physics.

Measurement has its own peculiar presuppositions. It must postulate 1) the homogeneity of the measured object; 2) its divisibility, as indicated by the units of the graduated instrument; 3) the permanence and fixity of the measurable species; 4) the invariance of dimensions; 5) the continuity of the object; 6) its spatial objectivity.[30] These are not empirical questions. If they are treated on an empirical level, the result will be a vicious circle.

What does physics measure? In the strict sense of the word, as Aquinas says, only quantity can be measured. All other mensurations have reference to operations on quantity.[31] This statement is in accord with the view of present-day physicists. As Herzfeld writes, "any statement to the physicist has meaning only if it is

[29] Cf. *supra*, p. 25. Also: "But relativity teaches nothing about the matter of events as distinguished from their spatio-temporal forms: nothing, that is, about lights and colours, the sounds, the odours, the hotnesses and coldnesses and so forth which we experience in space-time. For all that it has to tell us, these things may be of the very stuff of the universe," Nunn, T. P., "Anthropomorphism and Physics," *Proc. Brit. Acad.*, vol. xiii, 1926, p. 7.
[30] Spaier, A., *La Pensée et la Quantité*, Paris, 1937, pp. 322 ff. Though the author believes that quality itself can be measured, a view that will be considered below, his analysis of the postulates of measurement apply to the consideration of measuring quantity.
[31] *In Met.*, 10, 2, 1938.

quantitative."[32] Quality escapes measurement. It is an attribute that flows from form. It does not, as far as it is quality, proceed from the material component of corporeal being. Aquinas defines it as a mode of substance, a disposition of substance.[33] An intrinsic determination of substance, it does not order material parts in the manner of extension. It is a perfecting, actualizing attribute in the order of form. As a formal attribute, it is not subject to the laws of inertia that govern purely mechanical systems of physics, according to Newton's mechanics. Hence, by its function as an actualizing property on the level of form, it enables physics to avoid the infinite regress dictated by Newton's first law where all is inert and nothing is actualized.[34]

Quality as quality escapes physics. It does not, however, escape the physicist. His mental analysis bears upon the qualitative world of sensation. His system of measurement is built up from, and applied to, his observations of qualitative resemblance and difference. Quantity is only the plurality of parts. It is therefore always a quantity of *something* to which the parts belong. No scientist begins his work with mere plurality as such. He specifies the pluralized something (material object), without which the world of thought and of being would be unintelligible. He studies this material from the point of view of quantity. In the classification of phenomena, the physicist appeals to the qualitative order, especially in the early stages of his science. The distinction between positive and negative particles, waves and corpuscles, matter and energy, and the like are ultimately based on an insight into quality.[35]

In the fact that quality as such is not tractable in experiment lies one of the most important limitations of physics. Physics tends, Meyerson says, to reduce the qualitative world to the inertia of mere space.[36] Or as d'Abro has remarked, "The objective universe of science is thus noiseless, lightless, odourless."[37]

[32] *Art. cit.*, p. 40.
[33] I, 28, 2; I-II, 49, 2.
[34] John of St. Thomas, *Cursus Philosophicus*, Turin, 1937, vol. 1, p. 609.
[35] Cohen, M. and Nagel, E., *An Introduction to Logic and Scientific Method*, New York, 1934, p. 224 and p. 243.
[36] *Op. cit.*, p. 186.
[37] *The Evolution of Scientific Thought from Newton to Einstein*, New York, 1927, p. 412.

Quality, however, in a derivative sense does not completely elude the empirical method. As John of St. Thomas says,[34] quality determines quantity. All the objects of our sensation are, precisely because they are extended in material subjects, quantified qualities with the quality, according to the exigencies of its nature as a formal accident, determining the quantity which is the first and most characteristic accident of matter and the proximate subject of inherence for all others. It is possible then, by a study of the determined, quantified aspects of quality to arrive at some knowledge of its formal, qualitative determinant. Here we have a clue to justify the scientific method and to explain its success. It does not study heat, work, electricity, color, sound, and magnetism as formal qualities but only reaches their quantified aspects, their mechanical equivalents in the language of Boutroux.[38]

Matter is the vehicle of superior qualities. By a study of the vehicle, we can learn something of the qualities. When we study the quantified aspects of quality, we have not exhausted the fullness of quality itself. The mechanical equivalent of a thing is not the thing itself.[39] The two orders may be correlated without being identified. Loudness, for example, is determined by wave amplitude. Pitch is a function of wave length. By quantitative variations in each case, experiment achieves corresponding variations in the qualitative effects. This, however, does not justify the conclusions that the quantitative treatment of loudness and pitch has exhausted their realities. The wide use of such concepts as the Hamiltonian or the Laplacian in modern physics tends to throw into relief the homogeneous aspects of material phenomena which appear qualitatively different to common sense and to the realist in philosophy. But granted the validity of the quantitative approach which detects the common elements in such diverse fields as electrodynamics and hydrodynamics, light waves and matter waves, electromagnetism and gravitation, we have by a quantitative study by no means accounted for the qualitative heterogeneity of the related phenomena.[40]

[38] *La Contingence des Lois de la Nature*, Paris, 1929, pp. 63-4.
[39] *Ibid.*, p. 71.
[40] Nagel, E., *op. cit.*, p. 29.

Nagel has divided quality into additive and non-additive types.[41] But addition, strictly speaking, can apply only to the quantitative aspects of quality, not to the quality in itself. If we add weight to weight or light waves to light waves we can calculate by arithmetic addition and subtraction what the result will be. But we cannot do so with such properties as density, temperature, hardness, viscosity, compressibility, and the like.[42] The difference in such qualities from one substance to another affords proof that, though we may represent quantitative aspects of quality in mathematical formulae, our measurements have not exhausted their noetic plenitude. There is in matter a formal element which is not quantity and which the scientific method is consequently forced to ignore.[43]

Finally, it is only being realistic in the study of the physical world to define the scope of a science and then adhere strictly within the limits imposed by the definition itself (in the order of knowing) because they arise from the reality defined (in the order of being). The material world is a world of quantified quality. By its formal object, physics studies the quality only as quantified. This distinction justifies the procedure of physics. It also leaves room for the philosophical complement which physics cannot undertake but which looks, from another point of view, at the same subject matter.

Having seen the metaphysical limitations of measurement in its object, we turn now to the logical limitations of the process in its method. This involves two questions of particular importance: the general approximate character of measurement and the principle of indeterminism.

Our instruments of measurement are divided and subdivided into various units that we apply to the physical world, whether

[41] *Ibid.*, Chapter II.

[42] Campbell, N. R., *op. cit.*, p. 277 and p. 283.

[43] Here is a point where philosophy makes up for the inadequacy of physics. "For natural philosophy," Whitehead writes, "everything is in nature. We may not pick and choose. For us the red glow of the sunset should be as much part of nature as are the molecules and electric waves by which men of science would explain the phenomenon. It is for natural philosophy to analyze how these various elements of nature are connected," *Concept of Nature*, p. 29.

as pointer-readings, meter-sticks, or points on a geometrical curve. By the very nature of the process, we arrive at discrete results, even when we are applying measurement to a continum.[44]

On the other hand, we sometimes treat discrete data as continuous. In verifying such a simple principle as Boyle's law in physical chemistry, we may plot pressure against volume in a number of experiments with different elements; we then draw the smoothest possible curve to connect the points for the purposes of formulating the law.[45] Yet the original points, because of experimental error, may not all fall on the curve; indeed none of them might do so. Again, in dealing with a discrete medium of particles, we may, provided each element of volume contains a large number of corpuscles, regard the medium as continuous for purposes of mathematical analysis. Even in quantum theory, large aggregates of particles may be viewed as continuous and determinism again prevails.[46] In a practical sense this procedure is wholly justified. Yet at its best it can only yield a high degree of approximation.

When we are measuring length in the macroscopic world, we are oftentimes content with knowing centimeters, we do not regard the fractions that might result if the instrument were an eyepiece micrometer measuring in terms of microns. Or suppose, to take another example, that two men are asked the temperature of a given room. They might differ by a wide margin in their responses, and so a thermometer would be consulted to give the answer. They might read the result and accept the verdict of the instrument. But if we calibrated the instrument down to fractions of degrees and then to fractions of fractions, the difference in perception of the two men would again yield different answers. The thermometer has certainly refined and corrected the crude, common-sense conjecture on the temperature of the room. It has reached a degree of accuracy that is wholly satisfactory for practical purposes. But we must say that even the thermometer readings can only be interpreted as very high approximations.

[44] Schroedinger, *op. cit.*, pp. 72 ff.

[45] Lindsay and Margenau, *op. cit.*, pp. 14 ff.

[46] d'Abro, A., *The Decline of Mechanism*, pp. 183-5.

In this light, Whitehead has pointed out that one of the chief causes of the advance of science has been the development of scientific instruments in modern times.[47] This has led to a strong faith in the value of our instruments. After all, so long as men relied on the eye alone, it is said, observations were always subject to differences in visual accuracy: so also with all the senses. But the reading of an instrument is still the work of the eye. That there is no difference in the pointer-readings of two men is due not necessarily to the exact parallel of their vision-strength but perhaps to the imperfections of the instrument itself.[48] If it were calibrated finely enough, no two men might read it alike. As Eddington has said, no matter how finely we scale our degrees of accuracy, "molar physics has the last word in observation, for the observer himself is molar."[49]

Secondly, to make perfect instruments requires instruments equally delicate. How are we to make sure that two of them are exactly alike? Instruments are helpful tools and have reduced the margin of error in our measurements. But they are not perfect. We must continue to speak of phenomena in terms of approximation carried out to new decimal points but never measured with reliable accuracy in an absolute sense. The use of instruments to check the accuracy of instruments involves a vicious circle if the process remains on the purely empirical level. To escape from it, we examine by another method the sense perception which originates the process of measurement, participates in the checking of instruments, and finally takes the pointer-readings themselves. The differences in perception may still leave room for material inexactitude. However, the method of measurement can be formally

[47] *Science and the Modern World*, p. 161 ff.

[48] Whitehead, distinguishing perceptual objects, sense objects, and scientific objects, calls attention to the differences of perception, among men, on the level of perceptual objects, *Principles of Natural Knowledge*, p. 86. But even if his divisions and definitions were entirely correct, the refined character of our knowledge of scientific objects has not solved the problem of inaccuracy. These objects are subject, through the approximate character of every measurement, to the same inaccurate treatment which characterizes our measuring of macroscopic objects like a table. Our instruments have simply reduced these inaccuracies.

[49] *The Philosophy of Physical Science*, p. 77.

justified by being placed beyond the enclosure of a vicious circle. Man's self-knowledge makes him subject and object of his own actions. This may be called anthropomorphism. The appeal to sense perception, studied and examined by philosophy, may be termed a meaningless question by Bridgman and the Viennese school, since it does not submit to checking by the scientific method. But without it, we cannot have science, much less a rationally founded science.

The factor of interference is an important curb on the accuracy of measurement. In the macroscopic world, the physicist points out, the margin of error is so small that it makes no practical difference in the end result. But in the microscopic world, the factor of interference is important. Suppose that we are trying to measure the path of alpha rays by the cloud-chamber method designed by C. T. R. Wilson. This is done by indirect means. The principle employed consists in this, that when a gas, saturated with moisture, is quickly expanded, condensed vapor is formed. The alpha particles ionize the atoms of the gas along their tracks; at the sudden expansion minute drops are condensed on the ions. If the drops are immediately illuminated by an electric spark, they can be photographed. They thus represent the path of the alpha particles. But what have we actually measured? The path of the particles has certainly been deflected by the collision with the atoms in the gas; another item of interference is the electric spark. We can certainly claim to have approximated the tracks of the particles. But so long as we must interfere with the rays in order to measure them, our photograph must always remain an approximation. This is a serious consideration that plays a role in every measurement to determine quantity. But a thing, apart from its measurement, has no meaning in physics.

The Heisenberg principle of indeterminism has aroused much speculation among physicists and also among the positivists who wish to equate scientific knowledge with the whole of certitude. Though the principle has been given a wide variety of different interpretations, it simply states that we cannot measure position and velocity simultaneously. This definition can be best explained and defended by an example. Suppose that we are measuring a

fundamental particle like a proton or an electron. If we wish to know its position, we must observe its effect in scattering light or material particles. But since the experiment involves the exchange of energy in one way or another between the colliding particles, we are unable to determine the momentum of the original particle. In a similar way, measurements of momentum do not allow an accurate simultaneous determination of position. The more accurately we try to determine the one, by using, for example, light of a shorter wave length in the first experiment, the less accurate becomes our determination of the other. The result is that we can specify position and velocity simultaneously only in terms of probability.[50]

This principle of indeterminism, one of the foundation-stones of modern quantum mechanics, thus imposes a limit on observability—a limit that lies in the very nature of experiment. In classical mechanics, it was thought that if we knew the state of a physical system at a given instant, its state at any future instant could be accurately predicted by mechanical laws.[51] In quantum

[50] Objective indeterminism makes no sense. It is obvious that unless objectively there is something stable and determined with respect to which the indeterminism is said to exist, we could never even recognize or enunciate the principle of indeterminacy. Unless this determinate something is objectively real, the indeterminism described by the Heisenberg principle (which amounts to inaccuracy in measurement) could never be real either. The ontic implications of the Heisenberg principle is an argument for the reality of what traditional philosophy calls "form," "substance," and "nature."

[51] Laplace wrote: "We ought then to regard the present state of the universe as the effect of its anterior state and as the cause of the one which is to follow. Given for one instant an intelligence which could comprehend all the forces by which nature is animated, and the respective situation of the human beings who compose it—an intelligence sufficiently vast to submit these data to analysis—it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be more uncertain, and the future and the past would be present to its eyes. The human mind offers, in the perfection which it has been able to give to astronomy, a feeble idea of this intelligence. Its discovery in mechanics and geometry, added to that of universal gravity, have enabled it to comprehend in the same analytical expressions the past and the future states of the system of the world. Applying the same method to some other objects of its knowledge, it has succeeded in referring to general laws observed phenomena and in foreseeing those which given circumstances ought to produce," *Philosophical Essay on Probability,* New York, 1902, p. 4.

mechanics, only probable predictions can be made because of the Heisenberg principle which enforces limits on our knowledge.[52] As contemporary physicists are accustomed to say, the law of causality no longer applies in nature. But obviously causality does not have the same meaning for the physicist as for the philosopher. For the latter, it means entitative dependence; for the former it means the predictability of events from a knowledge of their previous states.[53] Causation, for the physicist, means the order of nature, and it is beginning to assume the meaning of our knowledge of that order. This raises the question of whether indeterminacy is subjective or objective.

In their popular works, men like Eddington and Jeans[54] have insisted that the principle is objective. Heisenberg also holds this opinion because, he says, the restoration of determinism would destroy quantum mechanics.[55] Opinion on this point must be reserved by such thinkers as the logical positivists. Their so-called physicalism forces all questions which are outside the scope of scientific method, into the category of the meaningless.

On the other hand, Planck and Einstein have insisted that indeterminism is only subjective, an inexactitude in our knowledge

[52] There are really two indeterminisms in modern physics: 1) That caused by the interaction between instrument and system; and 2) That caused by a lapse of time (considered quantum-mechanically) between the interference and the recording of the result. Cf. Tolman, R. C., *The Principles of Statistical Mechanics,* Oxford, 1938, p. 416 and p. 232.

[53] "I propose," writes Planck, "to commence the next stage with the simple and general proposition that an event is causally conditioned if it can be foretold with certainty," *Where Is Science Going?*, p. 45.

[54] Eddington, for instance, argued that religion became possible for the man of science after 1927, the year of the formulation of the Heisenberg principle. Probability equations in modern physics have been evoked to prove free will, to refute mechanistic biology, to explain evolution, and Sommerfeld has even argued that the soul is present illocally in the body, just as a corpuscle is associated with a wave in some indeterminate way. Cf. Frank, P., *Interpretations and Misinterpretations of Modern Physics,* Paris, 1938.

[55] *Op. cit.,* pp. 12-13.

of nature but not an indeterminism in nature itself, a temporary barrier but not a permanent limit.

The fact that physicists have not always kept in mind the distinction between the logical and ontological orders has considerably obscured their attitude toward the physical significance of the principle. To ask for the simultaneous specification of the position and momentum of a particle is, they hold, a meaningless question: therefore, there is in nature an inherent natural limit to measurement (equal at least to Planck's constant h). If a phenomenon is not measurable, it simply does not exist for physics, they add; the conclusion is that there is position without momentum and momentum without position in the real order.[56]

In interpreting the principle of uncertainty, Planck and Schroedinger have pointed out that the question of its status has been asked in the wrong way. It is not an empirical question to be settled by measurement. This would only impale it in a vicious circle. For so long as men rely on measurements to settle the question, the very conditions of the problem preclude the answer.[57] We can resolve the question only on the premise that there is a legitimate philosophical approach to matter in addition to the method of science. A question may be meaningless to the physicist with his method of mensuration and yet be very meaningful to the

[56] Pauli makes a distinction between indeterminism and our own ignorance. "Die Unterscheidung zwischen (prinzipieller) *Unbestimmtheit* und *Unbekanntheit* sind für die ganze Quantentheorie entscheidend. Dies möge erläutert werden am Beispeil einer Versuchsanordnung, bei welcher ein Lichtquant die Möglichkeit hat durch zwei Löcher zu treten und auf einem dahinterliegenden Schirm (im statischen Mittel bei oftmaliger Wiederhölung des Versuches) eine Beugungsfigur zu erzeugen. In diesem Fall ist es unbestimmt durch welches Loch das Lichtquant geflogen ist. Wenn dagegen eine Versuchsanordnung vorliegt bei der sicher nur ein Loch für das Lichtquant geöffnet ist, dann sagen wir es ist nicht bekannt, durch welches Loch das Lichtquant geflogen ist." "Die Allgemeine Prinzipien der Wellenmechanik," *Handbuch der Physik*, vol. 24, pp. 88-9. However, one may still ask why the path of the photon should be indetermined in the first case and unknown in the second. If we could measure their paths, both would turn out to be ontally determined. Indeterminism is a logical limit; it is not an ontal dislocation.

[57] Schroedinger, *op. cit.*, p. 116; Planck, *Wege zur physikalischen Erkenntnis*, p. 163.

philosopher searching after the more remote characteristics of matter by intellectual analysis. If the scientific method is to be the sole instrument for valid knowledge, then we shall continue to confound the order of being with the order of knowing and wind up in utter skepticism. Scientific method cannot even decide the question of the objectivity of knowledge. If it alone can exhaust reality, then reality is equated with the metrical aspects of matter. Posed from the philosophical viewpoint, the question of indeterminism is synonymous with the problem of nature's order. We shall return to this question in Chapter IV.

The problem of indeterminism is a pseudo-problem. It has arisen from an equivocation in the meaning of the word "determinism."[58] As Bertrand Russell says, "The Principle of Indeterminacy has to do with measurement not with causation (the order of nature)."[59] It is not an ontal fact. It is an epistemological limit of measurement. To substitute the latter for the former is as anthropomorphic as the nineteenth-century naiveté which contemporary scientists want to do away with in their science.

But if contempoprary quantum mechanics has been forced to abandon the search for an exact formulation of law in individual cases, it has nevertheless adopted a substitute expression of order and uniformity without which true science would be impossible. It is the substitute of statistics. By this means, physics seeks for ontal order at a lower level.[60]

In the present chapter, it has been noted that measurement is included in the point of view taken by physics on its subject-matter. The purpose of measurement is to give a numerical, not ontological, representation of reality. Measurement is limited ontally by the fact that it cannot resolve quality as quality into its forms. It is limited logically by being an approximation and by being subject to the principle of indeterminism. The mathematical character of measurement may now be discussed.

[58] Stebbing, L. S., *A Modern Introduction to Logic*, London, 1933, pp. 183-4.

[59] *The Scientific Outlook*, New York, 1931, p. 105.

[60] Maritain, J., *op. cit.*, p. 53.

CHAPTER III

Applied Mathematics

Statistics, so true in general, so fallacious in particular, as Gibbon said, is a way of studying the average fate over a large array, of realities which we cannot measure individually and which can be evaluated in individual cases only in terms of probability.

Though statistical mechanics has received peculiar stress with the advent of quantum theory which now rules the field in the study of atomic and subatomic particles, it was known and used in classical physics where the knowledge of the initial condition of an ensemble was inexact; where precise individual measurements (of molecules for example) were impossible for empirical reasons; and where exact computation was impracticable because of the large numbers involved.

Laplace, Poisson, and Bernoulli worked out theories of probability in mathematical terms. Maxwell and Boltzmann developed and applied statistics to phenomena of the kinetic-molecular theory. It was Maxwell's equations that were applied in such problems as the determination of the mean free path of molecules in a volume of gas and their average velocity. Boltzmann's outstanding contribution to classical physics was his mathematical interpretation of the second law of thermodynamics. His H-theorem, which calculates the tendency of molecules to approach equilibrium distribution, enables us to forecast with reasonable exactness the future behavior of a system of particles when our knowledge of their original state is incompletely specified.[1]

Before the advent of quantum mechanics, classical physics had also applied statistical methods to the study of radioactive decay. In phenomena of radioactivity, alpha-, beta-, and gamma-particles

[1] Maxwell had investigated the "probability distribution" of gases before Boltzmann's fundamental work was published. Hence the physical equation for determining the most probable state of a gas through statistical means is called the Maxwell-Boltzmann distribution law.

are liberated from atoms with the result that the radiating atoms of one element break down with time into simpler elements by a type of atom-smashing in the world of nature itself. By a simple mathematical equation, the time of decay of a definite fraction of an aggregate of atoms can be precisely computed, if the number of atoms present is known in advance. The time at which our analysis begins seems to have no effect in determining the fate of the aggregate. Half of an aggregate of radon atoms will break up within 3.825 days after our study is commenced, or they will survive the period; RaA has a half-life[2] of three minutes, RaB of 28.8 minutes, and so on. But though we cannot determine the fate of the single atom, we can, in dealing with large numbers, arrive at a very simple mathematical relation stating the half-life period of the aggregate. This precise calculation over large aggregates of atoms indicates that though the decay of the individual atom seems at first sight to be a random process, there is in reality an order that we have not been able to grasp.

In quantum mechanics, statistics are employed not only because of the practical difficulties that made it easier for classical physics to deal with large aggregates on a statistical basis. There is an additional theoretical difficulty in the Heisenberg principle whereby we can only state the probability-amplitude of an individual particle without being able simultaneously to specify its position and momentum.[3] The Schroedinger equation, which is fundamental to contemporary study of quantum phenomena, yields a statement of the most probable positions of a particle.[4] Applied to increasingly large numbers of particles, it can specify values with increasing accuracy. Finally, it becomes identical with the determinism of classical mechanics according to the Bohr correspondence principle.

Statistical mechanics has been especially fruitful in the study of thermodynamics. By virtue of its principles, we eliminate in a sense the idea of heat since we deal only with the potential

[2] Half-life period is the time required for half of the radioactive atoms present at a given moment to decay.

[3] Cf. *supra*, pp. 37 ff.

[4] Cf. Mayer and Mayer, *Statistical Mechanics*, New York, 1940, pp. 43 ff.

and kinetic energy of atoms themselves.[5] Applied to the second law of thermodynamics, statistics has led to the opinion that entropy has only a macroscopic meaning and that the behavior of individual systems of an ensemble is a tendency toward disorder in which only a probable prediction of future phenomena is possible. Because of this disordered movement which is amenable only to statistical treatment, a pail of water might conceivably freeze on a fire, it is said, instead of evaporating; or a stone might "fall upward."[6] Of course, such an opinion willingly admits that the odds are overwhelmingly against such wild possibilities. But having generalized the statistical analysis of macroscopic thermodynamic phenomena, it believes justified in viewing all rigidly entropic processes as a tendency toward disorder in which anything might happen.

The application of statistics is not a mere exercise in mathematics. It demands analysis on the part of the scientist to collect and classify data and to select, through judgments of relevance and irrelevance, those factors which are essential to a statistical treatment of a collection and those which are not.[7] Thus, contemporary physics has three statistical ways of treating particle phenomena. If there are n distinguishable particles, a modified Maxwell-Boltzmann distribution law can be applied. In the case of n indistinguishable particles with symmetric functions[8]—nuclei and atoms having an even number of particles and also photons treated as particles—the Einstein-Bose statistics can be applied. In the case of n indistinguishable particles subject to anti-symmetric restrictions—electrons, protons, neutrons, or nuclei and atoms having an odd number of such particles—the Fermi-Dirac distribution laws can be used.[9] Although the Boltzmann

[5] Bridgman, P. W., *The Nature of Thermodynamics*, Cambridge (Mass.), 1940, p. 100.

[6] *Ibid.*, pp. 162-164.

[7] Keynes, J. M., *Treatise on Probability*, London, 1921.

[8] A function is symmetric when the interchange of two fundamental particles does not involve changing the sign of the function. It is anti-symmetric when such an exchange results in the changing of the sign.

[9] Tolman, *op. cit.*, p. 367.

statistics is mathematically simpler than the others, it does not take into account the mechanical interaction of the particles.[10]

The widespread use of statistics in modern physics, especially since the advent of the Heisenberg principle, has led to the belief that all laws are merely statistical laws. But such a view is confuted by philosophical analysis. If there is an order in nature, if chance is, as Bacon said, the mark of our own ignorance rather than of nature's blunders, then statistics is merely a way of treating aggregates of phenomena, the individual cases of which we are unable, because of experimental difficulties or because of the large numbers of systems, to treat with the mathematical rigor that we use on the macroscopic world. Probability-amplitudes and apparent chance relationships are applied on the level of the individual only because of the experimental or computational difficulties. But from another point of view, statistics is an exact science like any other—with its own subject-matter, its own axioms, and its own conclusions.

Laplace defined probability as the ratio of favorable cases to unfavorable ones. In a more specific sense, this means that by analysis of a set of data over a suitable range we can arrive at a limiting recurring rate for a particular sample and calculate, by integrating the equation thus found, the distribution of the sample in the whole collective. It is apparent that once this limiting frequency value has been established, the proportions in the end-result do not change no matter how large the aggregate becomes.

The three important statistical theories in vogue in modern physics—the Boltzmann, Einstein-Bose, and Fermi-Dirac systems—start out by an assumption concerning the initial distribution of the particles. Boltzmann, supposing that molecules were absolutely elastic and spherical bodies—a concept that was rightly criticized by such men as Stallo and Mach—made the assumption that certain ranges of the states of the molecules were equally probable. Though the quantum statistics rejects Boltzmann's billiard-ball concept of particles, they are at one with him in certain fundamental conceptions concerning equal probabilities. The Einstein-Bose theory, instead of considering individual particles,

[10] Mayer and Mayer, *op. cit.*, pp. 63 ff.

assumes that each distribution of the whole is equally likely. The Fermi-Dirac system is founded on the assumption that a distribution has equal probabilities only when all the particles have different energies and are in different states.[11] But the assumptions concerning the initial distributions which underlie each of the three theories are not wholly without contact in the real world. The computations to which they each give rise can be tested by experimental measurements. All three systems have proved verifiable within their respective domains of application.[12] It is a case, in the language of de Morgan, of using experiments not to draw theories from but to test theories by. The test justifies in some sense the original assumptions and shows that the theory as a whole, in both its physical presuppositions and its mathematical development, has somehow come into real contact with the real world. The average is not a complete artefact, even though it may not be in 1-to-1 correspondence with reality.

Statistics has been contrasted with the so-called causal laws of physics which enable us to make accurate and not merely probable predictions. But this distinction cannot be maintained on closer analysis. Statistics is a science, like any other mathematical (or physico-mathematical) discipline. It differs from the other mathematical sciences not in its accuracy but in its subject-matter.[13] We are ignorant of the state of individual systems. Hence we begin with *averages* in the initial distribution. From this, however, we can accurately forecast the *averages* in the end-distribution. In view of this *exact* correlation, the individuals which form the average have somehow been obeying order and law. What statistics does is to reinforce the so-called principle of causation. This principle is not an empirical problem. The final answer as to whether nature is ordered or not must be based on intellectual analysis.

Indeed, statistics is a case for the principle of nature's uniformity in two ways: Firstly, if we start off with only probable prem-

[11] de Broglie, L., *Matière et Lumière*, Paris, 1937, p. 255.
[12] v. Mises, R., *Wahrscheinlichkeit, Statistik, und Wahrheit*, Vienna, 1936, pp. 240-242; Keynes, *op. cit.*, p. 391.
[13] v. Mises, *op. cit.*, p. 35.

ises, we can attain only a probable conclusion. Therefore, there is a form of determinism between our point of departure and our end-result.[14] Probability does not arise from the unpredictability, in individual cases, of nature in itself. It comes from our ignorance of the premises on which actual prediction must be based. When we cannot predict the future state of a system from knowledge of its previous state, this is so only because we cannot know the previous state. But since probable premises, in individual cases, can yield probable conclusions and since the probability can be exactly stated, we have not abandoned the determinism of the individual but sought it, as Maritain remarks, at a lower level. Secondly, over large aggregates, though we disregard the fate of the individuals in an aggregate, determinism reappears in the convergence of accurate predictions toward the limit of one; quantum mechanics approaches classical mechanics according to the correspondence principle. These two facts seem to argue against the views of certain modern physicists that because of our ignorance of nature, as shown in statistics, we must abandon objective determinism and equate scientific measurements with the whole course of nature. Such a view is a most literal anthropomorphism, of the type which Protagoras espoused, when he wrote that man's mind is the measure of all things.

A similar answer must eventually be invoked against the problems raised by the statistical treatment of thermodynamics. The so-called disorder is only an apparent one, a disorder in knowledge rather than of being. The ordered obedience of macroscopic thermodynamical phenomena to the law of entropy is proof of this fact. Statistically, we cannot speak of entropic individuals in thermodynamics since entropy does not exist on the level of the individual by definition. In the domain where heat exists, entropy holds. Statistics may explain away heat by reducing it to kinetic and potential energy. We may still wonder whether this statistical treatment really exhausts the subject. The macroscopic tendency of matter to produce unusable energy is still a challenging fact. The skepticism towards all law on the basis of the statistical treatment of thermodynamics is grounded on the homocentric belief

[14] Tolman, *op. cit.*, p. 210.

that we have proved the lack of order in nature simply by our failure to detect that order, the belief that the apparent disorder is a real one, that out of the disorder may arise in chance form such ordered happenings as the freezing of water on a fire or the falling of a stone upward. The disorder of increasing entropy is in reality only an order of a different type from that of reversible processes; this is shown by the ordered macroscopic phenomena which result and which prove deeply below the surface that the individual particles are obeying an order which eludes us but which is none the less real, ineluctable, and compelling for all that. We cannot simply conclude from the complexities in understanding or measuring a thing that it does not exist. If the universe is ordered as a whole and in its parts, disorder is no more the natural effect of order than chance can be the natural effect of purpose.[15]

Probability is only a mental state. It is not a sort of excluded-middle which reigns in the objective world. In themselves, relations affirmed by judgment are either true or false. When the evidence is not sufficient for us to attain certitude with regard to their truth or falsity, we may then arrive at a problematic judgment based on lesser evidence. As Plato put it, truth is to opinion as being is to becoming.

The distinction must be made between the empirical and logical treatment of probability. It is perfectly within the scope of physics, and of statistics in general, to express its probabilities in mathematical terms. Mathematics is the exact language demanded by empirical science. But mathematics is not logic. The mathematics of probability is a mathematical system based on numerical analysis. It can neither support demonstrative logic nor contradict it. It is on a different level. Yet outside of the domain of statistics, there is a logic of probability which differs both from apodictic reasoning and from the mathematics of probability. If it be asked whether Shakespeare had a long formal education, whether another war is likely within twenty-five years, or whether Plato wrote

[15] "If this law (the second law of thermodynamics) governed world development, God would have created a most improbable initial constellation which, left to itself, could only deterioriate into a growing disorder of increasing probability," Riezler, *op. cit.*, p. 16.

the dialogues in the order suggested by Lutoslawski, only a probable answer can be given—an answer which is outside the scope of mathematical expression but which is nevertheless a perfectly legitimate region of knowledge. Newman developed a logic based on convergent probabilities. Aristotle himself devotes a whole section of his organon, the *Topics,* to dialectical or probable argument. Statistics, as far as it obeys mathematical laws, is an exact science, although errors can easily arise in interpretation within the field where statistics are applied. When the physicist goes beyond his figures to say that matter is indetermined, he does what he says he should never do, namely, he interprets.

The foregoing discussion has already indicated the fact that the results of physical measurement are expressed in mathematical form. Mathematics is the language of modern physics. If physics deals with matter in terms of its quantitative aspects, it is readily understandable that mathematics, the science of quantity, should have a fundamental role in empirical study. Aquinas points out that the quantity of a being is known through measurement and that measurement is based on unity and number.[16] After Descartes had made quantity the essence of a body and mathematized the philosophic study of the universe, mathematics deposed philosophy as the *scientia rectrix* of empirical knowledge. But philosophical-minded physicists have failed to appreciate the epistemological significance of mathematical physics, with the result that the science of measurable reality has tended to identify reality with its measurable aspects. Mathematical entities in physics are a stenographic method of expressing physical concepts. Strictly speaking, the information contained or implied in a differential equation or "world" geometry could be stated in physical language.[17] But mathematics is brief, systematic, and exact. The brevity of an equation as compared with the cumbersome form of ordinary language is self-evident. The systematic interrelatedness of the various entities of a mathematical system enables us to reason with great ease and economy.[18] Finally, the symbolic character of mathematical entities

[16] *In Met.* 10, 2 (*passim*).
[17] Dantzig, T., *Number, the Language of Science,* New York, 1933, p. 233.
[18] Dantzig, T., *Aspects of Science,* New York, 1937, p. 75.

makes for a greater exactitude than would be possible, in the language of sense-intuition, when dealing with the metrical aspects of matter. It is this "objective" representation of experience in number-form which has led physicists to believe that rigorous attention to the mathematical symbolism strips their science of its anthropomorphic character.[19]

Mathematics is a science of its own right. It is indeed a perfect type of science, a *scientia propter quid,* in which the reasons for the attribution of a predicate to a subject are seen within the subject itself.[20] But by its subject-matter, it is circumscribed. It is the study of idealized quantity. As a *scientia propter quid,* it can demonstrate why one quantity (or aspect of quantity) is contained within another. It cannot perform the same function in the world of real being. Quantity is not co-terminous with reality. It is in fact the lowest kind of being. In the real world, we always have a quantity of *something.* What that something is escapes the grasp of mathematics. If mathematics is a *scientia propter quid,* it detaches quantity from its accidental status in the ontal world. It considers quantity as an independent, substantial entity for purposes of study. It deduces its various relationships. Not concerned with existential reality, truth in mathematics is not the conformity of thought with thing but of thought with thought—the legitimate sphere of the coherence theory of truth. On this premise, we can understand how there can be Euclidian, Riemannian, Lobatschevskian, and *n* geometries; how mathematically they can all be valid. In the physical sphere, it is another and perhaps insoluble question to ask whether space is Euclidian or not. In pure mathematics, space may be defined in any way the mathematician chooses so long as he does not, in his system, violate the principle of contradiction.[21]

[19] Nunn, T. P., *Anthropomorphism and Physics,* London, 1928, p. 8.

[20] Maritain, *op. cit.,* pp. 82-3.

[21] "Mathematical achievement shall be measured by standards which are peculiar to the mathematicians. These standards are independent of the crude reality of our senses. They are: freedom from logical contradiction, the generality of laws governing the created form, the kinship which exists between this new form and those which have preceded it," Dantzig, *Number, the Language of Science,* p. 231.

This description applies only to the mathematics, which came to maturity, and perhaps even into childhood, during modern times. Such modern mathematics—whether its foundations be called *logical,* as in the works of Whitehead and Russell, or *empirical,* as in the works of a host of modern thinkers—is inductive in character; inclined to emphasize geometry as more fundamental than the science of number; and in general disposed to substitute for the concept of unity the notion of mathematical infinity which found fruitful applications only in the last several centuries. Classical mathematics is inclined to emphasize that each number is a different *species* rather than the limit of a continuous series. It is only this modern mathematics which is to be gauged solely by the principle of consistency.

The problem is to be explored much further than present limits allow. Its solution, it would appear, is not crucial for developments in the following pages which, when referring to mathematics, naturally emphasize the modern inductive type displayed by mathematical physics.

The idealized (abstract) character of mathematical entities prescinds from the idea of actuality. As employed, however, in physics, mathematics is no longer pure but applied.[22] It is then no longer a science of idealized forms as such. It seeks to bring the world into conformity with its abstract entities. Here lies the approximate character of physics that was already outlined in discussing the limits of measurement. Extended reality does not obey abstract mathematics which deals with perfect spheres, whole numbers, holomorphic functions, and other idealized entities.[23] To obtain continuous curves in the establishment of a relationship like that expressed in Boyle's law, we must interpolate values. We must content ourselves in measurement with a great but not the greatest number of decimal points and often with orders of magnitude without being able to specify the figures within those orders. Though we may be working with discrete elements, we consider

[22] Cohen, M. R., *Reason and Nature,* New York, 1932, pp. 173 ff. Einstein (*Geometrie und Erfahrung,* Berlin, 1921, p. 8), makes a distinction between axiomatic and practical geometry.

[23] d'Abro, A., *Evolution of Scientific Thought from Newton to Einstein,* p. 34.

them to form a continuum so that the powerful tool of mathematical analysis (the calculus) may be applied. In short, the physical world can only approximate mathematical abstractions. As Einstein says, "As far as the statements of mathematics relate to reality, they are not certain; and as far as they are certain, they do not relate to reality."[24]

Whitehead has worked out a theory to bridge the gap between the physical and mathematical and thus to make possible the application of mathematical measurements to a physical reality. It is the method of "extensive abstraction." Mathematics in its pure form, Whitehead argues, does away with spatial characteristics. It treats them as inextended points. It does away with temporal characteristics, treating them as durationless instants. The problem is one of reconciling the point-moment mathematical scheme and other such constructions with which science deals and the sensible, extended, enduring reality with which it begins.

To solve the problem, Whitehead proposes that we consider an intellectual movement of convergence to simplicity in which quantities such as volume or duration are allowed to grow smaller and smaller, approaching—but never reaching—an ideal limit. If we are measuring volume, we can, Whitehead states, conceive of a nest of Chinese boxes. These unfold one after another in the analogy. There is an indefinite sequence with each box being smaller than the one before it. Though the series may tend toward an ideal limit, the quantitative expression never reaches it. The smallest box still has volume. It is always extended by whatever small amount.[25] Whitehead compares his method to the procedure of the calculus "in the region of numerical calculation, namely, it converts a process of approximation into an instrument of exact thought."[26] However small we let our element of volume decrease, it is always extended by an amount, however small. Time calculation can be treated in a simular way.[27] By retaining the physical

[24] Einstein, *op. cit.*, pp. 103-4.
[25] *Concept of Nature*, pp. 80-81.
[26] *Principles of Natural Knowledge*, p. 76.
[27] Whitehead sums up his method of extensive abstraction thus: "A set of events is called an 'abstractive class' when (i) of any two of its members one extends over the other, and (ii) there is no event which is extended over by every other event of the set.

"The properties of an abstractive class secure that its members form a series in which the predecessors extend over their successors, and that the extension of the members of the series (as we pass towards the 'converging end,' comprising the smaller numbers) diminishes without limit; so that there is no end to the series in this direction along it and the diminution of the extension finally excludes any assignable event. Thus any property of the individual events which survives throughout members of the series as we pass towards the converging end is a property belonging to an ideal simplicity which is beyond that of any one assignable event. There is no event which the series marks out, but the series itself is a route of approximation towards an ideal simplicity of 'content,'" *ibid.*, p. 104.

characteristics of—to use Whitehead's term—an event, however small it becomes, the method of extensive abstraction aims to provide a logical basis for the application of mathematics to physical data. Because of its similarity to the theory of the calculus, a likeness which Whitehead himself avows, the method of "extensive abstraction" has struck responsive chords in physicists who see in it a way of keeping their science on a physical basis.

But Whitehead has only restated the problem. He has not solved it. The problem that attracts him can be solved in terms of the traditional notion of abstraction. In mathematics, the mind prescinds from all sensible attributes of bodies except their quantity. It considers this in the abstract apart from its physical existence. In returning to matter, man's intellect applies its mathematical reasoning. It must recognize in the applications of numbers and lines that it can only approximate mathematical entities in the physical world. Whitehead's method cannot substitute for this traditional notion of abstraction without which mathematics cannot be explained.

The mind must work with the "ideal limit" to study its characters and to derive their laws. The line between this "limit" and the members of the convergent series is not continuous, to borrow a term from mathematics. There is a discretum, a gap. It divides mathematics from mathematical physics, exactitude from approximation, the abstract from the concrete, and between these couples there is no middle term. Whitehead's method does not bridge the gap. His problem can only find a realistic treatment if we bear

in mind the division of mathematical and physical sciences based upon the degrees of abstraction. Mathematics is one thing. Physics is quite another. When we apply to the physical world the idealized forms of mathematics, the result is an approximation. The mathematical is not an ideal case of the physical in the sense of calculus where *ideal* means *limit*. It is an ideal of the physical in the sense of traditional abstraction. In the method of "extensive abstraction," mathematics is not differentiated from the physical sciences. The difference which Whitehead proposed is one which "excludes any assignable" distinguishing event, a terminology which Whitehead adopts from the calculus. He transfers the methods of calculus from their legitimate sphere to that of intellectual operations which are no more pure quantity than quantity is pure spirit. Whitehead, here as in other cases, merely restates problems which he sets out to solve.

Mathematics is not the plenary explanation of reality. Bertrand Russell remarks, "Physics is mathematical, not because we know so much about the physical world but because we know so little; it is only its mathematical properties that we can discover."[28] Even in mathematical physics, mathematics must be supplemented by the non-mathematical if its statements are to have any meaning in the physical world. Facts are not proved by a mathematical equation except in a derivative sense, when other facts have been previously supplied by experiment. Mathematics affords a way of describing experiments and observation, reasoning about them, and generalizing these conclusions. It cannot take their place.[29] "Mathematics is neither a description of nature nor an explanation of its operation," writes Boyer. "It is not concerned with physical motion or with the metaphysical generation of quantities. It is merely the symbolic logic of possible relations, and as such is concerned with neither approximate nor absolute truth. That is, mathematics determines what conclusions will follow logically from given premises."[30]

[28] *Philosophy*, New York, 1927, p. 157. The intellectualist will not agree with Russell's view that the empirical method is the only approach to reality.
[29] Thompson, W. R., *Science and Common Sense*, New York, 1937, p. 124.
[30] Boyer, C., *The Concept of the Calculus*, New York, 1939, p. 308.

In present-day physics, the physical basis of mathematical formulae is oftentimes neglected both by preference and by practice. The new mathematical physics has, we are told, forced us to abandon such constructs as models and mechanical theories and to substitute a schema of mathematical equations. The result is that physics is becoming more and more mathematical and less and less capable of tracing its mathematical complexities to any real counterparts in the physical world. This growingly abstract character of physics, though it has obvious advantages, is a definite danger to the noetic stability of the science. As we ascend from the world of sense experience into the stratosphere of mathematical abstractions, physics may awaken to find that it has lost contact with the real world which it aims to study and explain. Physics, if it is to remain physics, cannot substitute the mathematical world for the data of experiment. Without radiation, Bohr's formula for the hydrogen spectrum would be a mere arithmetical fiction. Without the law of gravitation, the equations of dynamics in classical physics would have remained only a source of mathematical exercises.[31] "Mathematics," Herzfeld notes, "is only a tool, a shorthand way of expression, but cannot add anything to the physical concept, although it might occasionally suggest a physical law because its mathematical expression might be particularly simple."[32] Tool here is equivalent to formal object.

[31] Dantzig, T., *Aspects of Science*, p. 251.
[32] "The Frontiers of Modern Physics and Philosophy," p. 40.

CHAPTER IV

Empirical Law

Law in physics is not merely a mathematical equation. It is a physico-mathematical equation, a physical relation stated in mathematical form. Since Mill's time, the term "law" has been used to express a uniformity of connection between phenomena.

In the strict sense, "law," as applied to the irrational world is a misnomer. Aquinas noted that the word stems from the Latin "ligare" meaning "to bind."[1] Only rational creatures can be obligated by a rule or plan. The irrational world has no duties.[2] It is only by analogy, as Aquinas states, that the concept of law can be applied to irrational creatures.[3] He viewed law as a rule or measure of operations, according to which an agent is led to act or not to act.[4] He pointed out that every creature was subject to law, since, not being the author of its own being, it is not the author of its own purpose.[5] He viewed creatures as endowed with natural tendencies to seek their ends.[6] Law is an expression of natural tendency.

Final causes are in a sense the primary causes in nature: without a fore-determined end for the activity of creatures, there would not be a sufficient reason why one effect should flow from a given action rather than another.[7] It was these natural tendencies of creatures toward their proper ends that Aquinas called laws of nature.[8] In their very essence then is the notion of end, the striving of being to perfect itself according to the intentions carved into

[1] I-II, 90, 1.
[2] *Cont. Gent.* III, 104.
[3] I-II, 91, 2.
[4] I-II, 90, 1.
[5] I-II, 5, 6.
[6] I-II, 84, 3.
[7] *Cont. Gent.* III, 2.
[8] *In De Div. Nom.* X, 1.

its nature. The schoolmen did not seek mechanical laws of matter in a special science. They rendered matter intelligible in the only way that it can be so rendered. If man and matter are without purpose and goal by nature, then whim can, and should, rule the world and decide its destiny. The schoolmen, seeking God's laws in the things He made, found material being insufficient unto itself. They regarded it in the light of purpose and finality. Such notions the scientific method cannot touch. Yet they remain as challenging facts to thinking men.

Law always implies finality. It is a directive plan of action toward an end.[9] In human action, law is apprehended by the agent himself, who directs his own nature toward its end. In the subhuman world, cognition is likewise necessary for law. Not being possible, however, in the mineral, plant, and animal world, it exists in the mind of God who knows the ends of the subintelligent agents and directs these beings toward their preconceived goals. In the philosophical sense, laws are therefore tendencies in the order of finality.

In physics, where finality, not being susceptible to quantitative measurement, is quite naturally not considered, law has come to mean something different. It is a generalization of the quantitative correlations which are empirically observed and measured. Facts and laws are thus not radically distinct.[10] Laws, in general are a universalization of facts. Our language bears witness to this relationship. We are inclined to speak of the laws themselves as facts and to say, for example, "it is a fact that force equals mass times acceleration" or "it is a fact that electric current equals electromotive force over resistance."[11] "When people say that they appeal to facts they usually appeal to well-established laws," as

[9] I-II, 93, 3.
[10] Lalande, A., *Théorie de l'Induction et de l'Expérimentation,* Paris, 1929, p. 5.
[11] Cohen and Nagel, *op. cit.,* pp. 217-8, distinguish four meanings of the word "fact": a) Discriminated elements in sense perception like the lines of a spectrum or pointer-readings which are referred to as signs of facts rather than the facts themselves; b) Particular propositions stating a relation observed between *this thing* and *that thing* but not going beyond actual here-and-now observation; and c) General propositions, universalizing the conclusions of b; and d) The existence of a correlation between things existing in space and time.

Ritchie notes, "but they often think that they mean an appeal to sense-perception, to particular events."[12] In the stricter sense, the relations instanced above are laws. They generalize the measured associations found in experiment. Campbell argues that such qualitative statements as the description of the properties of substances in chemically identifying the elements, for example, are also laws.[13] But scientists do not refer to such phenomena as "laws." Law has a more precise sense. It denotes mathematical correlations, universalizing the results of experiment, formulating in a general way a physico-mathematical "fact."

Law differs from theory in that the former is based on direct empirical evidence.[14] It is an experimental generalization. If we may speak of actually observed and measured correlations as "facts,"—a common practice as was mentioned above—then, "Laws merely represent facts, collect them, describe them in a formula. They may be true or false; and they are true so far, and only so far, as they do represent facts."[15] They are then simply a generalization of experimental results.[16] Theories, on the other hand, are not susceptible of direct experimental verification. They are meaningful suppositions, hypothetically entertained. By them, the scientist seeks to account for observed laws. But the laws do not depend, as is sometimes argued,[17] on the theories which render them intelligible. Kirkoff's law is true regardless of our theory of electric circuits. Hooke's law does not depend on the theoretical account we give of stresses and strains. Laws are empirically observed. They do not share the epistemological insecurity of physical theories.[18] The latter may come and go. The laws remain.[19]

[12] Ritchie, *op. cit.*, p. 155.
[13] *Physics: the Elements*, Cambridge, 1920, pp. 47 ff.
[14] *Ibid.*, p. 130.
[15] Schmidt, K., "The Existential Status of Facts and Laws in Physics," *The Monist*, vol. 43, p. 162.
[16] Poincaré, H., *La Valeur, de la Science*, Paris, 1914, p. 142.
[17] Cf. Duhem, *op. cit.*, p. 254; also Sorel, G., "Les Preóccupations Métaphysique des Physiciens Modernes," *Revue de Métaphysique et Morale*, vol. 13, p. 871.
[18] Lindsay and Margenau, *op. cit.*, pp. 20-1.
[19] It need hardly be mentioned that the terminology of physicists is sometimes rather loose; sometimes the distinction between law and theory made above is not observed. In such cases, the inconsistency may be signalized by the philosopher. We are inclined, for example, to speak of the law of gravitation which is not a law in the strictest sense but partakes of a theory. Lindsay and Margenau, *ibid.*, pp. 22-23.

A physical law is formulated in a mathematical equation. The uniformity of association generalized by law can be best expressed in the exact, universalizing language of number. The differential equations which are the usual mode of expression are both concise in form and general in content. By mathematical development, we can make them explicitly applicable to the particular problems of the general case.[20] They depend, it was noted in the discussion of the procedure of measurement, on the function concept which expresses ratios between quantities, ratios that are yielded by experiment.[21] Stated in this convenient form of differential equations, the laws of physics thus enable us to calculate one quantity from our knowledge of another (or others) of which it is a function and to which it is related by a definite ratio. As Planck has noted, "Every statement is a physical law which expresses a fixed, inviolable valid correspondence between measurable physical magnitudes, a correspondence which permits one of these magnitudes to be calculated when the others are known through measurement."[22]

Planck's analysis is also important for its emphasis on the physical nature of the magnitudes involved. It is false or at least equivocal to say, as does Poincaré, that a law is a differential equation.[23] Equations are merely the formal way of expressing laws. The concepts of mathematical physics represent—or at least have reference to—physical phenomena. Unless, as was noted above, the material foundations of physics be kept in mind, physics will be emptied of the physical.

Ernst Mach, one of the seminal minds of the present-day epistemology of science, held that law is merely an economy of thought. Man tends to make things easy for himself.[24] Economy is of the

[20] Campbell, N. R., *Measurement and Calculation*, p. 218.
[21] Bridgman, P. W., *Dimensional Analysis*, p. 99.
[22] *Wege zur Physikalische Erkenntnis*, p. 148.
[23] "Une loi pour nous . . . en un mot, c'est une équation différéntielle," *op. cit.*, p. 174.
[24] *Die Mechanik in ihrer Entwicklung*, Leipzig, 1904, pp. 6-7.

very essence of science. Physics aims to make future experiments unnecessary to the extent in fact that laws are nothing but concise, economic formulae which enable man to live and to learn with as little effort as possible. The results of science could be attained without method. However, because of the brevity of life and as a convenience of memory, man finds it profitable to summarize his thoughts in the most economic way.[25] These summaries are scientific laws. So, at any rate, says Mach.

The counter argument is not against the view that laws economize thought, but that for Mach they seem to have no other references. As Aristotle noted, science deals with universals, i.e., with general principles common to many things. All men are scientists, in the word's widest sense, because they all desire to know. Knowledge by its very nature consists in the discovery of the one in the many, the general in the particular, or, in the language of modern physics, the discovery of the invariants in change. Economy is thus the natural result, it is indeed the concomitant, of knowledge. But it is not the only aim of science. It is not even the chief aim. We may distinguish also between the practical and the speculative sciences. The latter seeks knowledge for its own sake, the former for the sake of action. Mach does not make this distinction. The result is that he does not arrive at the true nature of knowledge. Hence, he does not grasp the relation of economy to science. Knowledge or science is a search after causes. When we reach causes, whether they be formal, final, material or efficient, we have economized thought. But we have done so only because a knowledge of causes yields (from the objective world) the one, the general, the invariant, in short, the universal with which science deals.

It is not sufficient to say that science is a mere economy of thought unless we are willing to recognize that there is an "economy" of being itself with which knowledge enters into correspondence. Otherwise, we must espouse nominalism or idealism. We are able to reach generalities in knowledge only because there are generalities in being which measures our knowledge. If we have not misinterpreted Mach, he does not accept this extreme view of

[25] *Ibid.*, p. 530.

idealism. But his concept of science as a mere economy of effort without further qualification can easily lead to subjectivism, as indeed it has since done among those who came under Mach's influence.

Interpreted in the fashion we have tried to indicate, the concept of law as a mental economy can find a real place in an organic philosophy of science. There is likewise room for Poincaré's philosophy of scientific laws if we search for the kernel of truth it contains and which, as Augustine said, can be found in every false system of philosophy.

Poincaré held that scientific laws, as we know them, are conventions. In this view, he was naturally influenced by his mathematical genius.[26] He perceived that there can be many valid systems of mathematics. Why do we adopt the Euclidian scheme in preference to other geometries? Because, he said, it is convenient. In mechanics, we find that our principles are not susceptible to direct experimental proof. We continue to use them out of convention. But this convention, he adds, is not completely arbitrary. Certain experiments show us why it would be suitable.[27] The conventions were accepted by the founders of the science who were led on by experiments to formulate them. The experiments justify the conventions.[28] The idea of force, for example, arises from a sense of effort; the concept of energy can be better appreciated by comparison with our own activity; the idea of mass can be grasped by the sensation of holding a heavy object. All these comparisons seem rather crude to the advanced knowledge of the scientist today. But still they lie somewhere beneath the surface of his general laws.

In order to reconcile being and knowledge and to avoid the extremes of anthropomorphism which Poincaré tries to eliminate

[26] Bavink, B., *Ergebnisse und Probleme der Naturwissenschaft,* Leipzig, 1933, p. 220.

[27] *Science et Hypothèse,* Paris, 1916, p. 163.

[28] "La loi d'accélération, lá régle de la composition des forces ne sont-elles donc que des conventions arbitraires? Conventions, oui; arbitraires, non; elles le seraient si on perdrait de vue les expériences qui ont conduit les fondateurs de la science à les adopter, et qui, si imparfaites qu'elles soient, suffisent pour les justifier. Il est bon que de temps en temps on ramène notre attention sur l'origine expérimentelle de ces conventions," *ibid.*, pp. 133-134.

and of cosmological agnosticism which conventionalism would logically lead him to adopt, the traditional notion of analogy may be applied. Granted that we have only a feeble knowledge of such elusive realities as force, energy, mass, and so on, still there is room for at least an analogical correspondence of phenomena and the psycho-physical cognition by which we grasp at first what the phenomena are and how they relate. The same parallel may be adopted in cases of other laws. It is this analogical correspondence which frees the so-called conventions from their purely arbitrary character. The mind is in contact with a real object, not merely with a mental figment. Poincaré himself seems to state this view in rather explicit terms, though his thought as a whole indicates that he did not appreciate the notion of analogy which he suggested. The scientist does not create the scientific fact out of nothing, he says. He derives it from the crude fact. Hence, he does not make a fact in a free and arbitrary way. His freedom is always limited by the material with which he works.[29] On his own testimony, Poincaré is not an agnostic. His concept of scientific law, which he traced back to its crude origins, can meet traditional philosophy through the notion of analogy. It is analogy that explains why the conventions are not arbitrary and why they are somehow in correspondence with reality.[30] The crude ideas of force, mass, and so on are not without deep meaning. Pure conventionalism would lead to skepticism and subjectivism.[31]

[29] *La Valeur de la Science,* p. 232.

[30] "Wenn ich mir willkürlich Naturgesetze zurechtlege und dann auf Grund derselben Maschinen erfinde, so funktionieren diese nicht: auf Grund willkürlichen Annahmen kann ich nicht prophezeien, wass die gebauten Maschinen leisten oder ob sie überhaupt etwas leisten; denn die Natur richtet sich nicht nach willkürlichen Konventionen," Becher, E., *Weltgebäude, Weltgesetze, Weltentwicklung,* Berlin, 1915, p. 9. Becher's words are of such explosive force against subjectivism in science that it is difficult to see how he could maintain, as he did, that objectivity was a matter of only high probability.

[31] In mathematics only can we begin with conventions and still be within the limits even of common sense which knows that a fall in obedience to the law of gravity or a shock in obedience to laws of electricity are not simply experienced because it is conventional to do so but because there are realities that impose themselves on man rather than obey his wishes.

It is these two extremes that Karl Pearson in his attitude toward scientific laws comes to accept. As a positivist, he is clearly influenced by Mach in his belief that a law of nature is "a *résumé* in mental shorthand, which replaces for us a lengthy description of the sequences among our sense impressions."[32] But for him laws are not discoveries. They are inventions. "Law in the scientific sense is thus essentially a product of the human mind and has no meaning apart from man."[33]

The idealism of Pearson is contravened by both reason and experience. If scientific laws enable us to predict future phenomena, then they are not mere mental constructs. They are ontologically valid. Science is not an arbitrary fiction of the individual human mind. It begins in experience. Experience checks it. The fact that the empirical generalizations which we call the laws of nature are reliable guides to our knowledge of what future experiment will produce is evidence that they are not the caprice of man but have at least an analogical correspondence with a world that is truly objective."[34]

Pearson is a positivist in his odium metaphysicum.[35] He glorifies the scientific method as the sole legitimate organon. It is the virtue of the positivists to insist that scientific method be freed as far as possible from all extraneous ideas that warp the unity of the science.[36] It is their vice to belittle the vision, imagination, physical insight, and emotional warmth which are the tools of the original thinker in science. So also is it their vice in philosophy to take over the scientific method and to attempt its application, with the same rigorous purism, to all knowledge (and for all ethics too, whatever that term may mean to a positivist.) It is only in prob-

[32] *The Grammar of Science,* London, 1900, pp. 80-87.

[33] *Ibid.,* p. 7.

[34] Bavink, *op. cit.,* p. 242.

[35] *Op. cit.,* pp. 14 ff.

[36] "Now, in Greek, it (method) literally means *a way, or path, of transit.* Hence, the first idea of Method is a progressive transition from one step in any course to another; and where the word Method is applied with reference to many such transitions in continuity, it necessarily implies a Principle of *UNITY WITH PROGRESSION,* Coleridge, S., *Coleridge's Treatise on Method,* ed., A. D. Snyder, London, 1934, p. 2. (Italics and capitals are in text.)

lems where the data are quantified, says the positivists, that we can expect to apply true science. The method of approaching the problems is to look for mathematical relations. If the positivists leave room for philosophy, it is to achieve a synthesis of the sciences or to perform the functions of logic in clarifying the meaning of scientific concepts.

Positivism renounces the search after causes. It insists on mathematizing knowledge through and through. The highest act of knowledge consists in measurement and the discovery of empirical law. Hypotheses must be eliminated altogether or be reduced to the mathematical background upon which numerical laws may be projected. As Comte wrote, "Every hypothesis, in order to be really capable of being judged, ought to bear upon the laws of phenomena exclusively and never on their mode of production."[37] Measurement alone is meaningful.

Avenarius, for example, proposed a philosophy of "pure experience" in which the function of the scientist is only to observe and report data.[38] There is no place here for hypotheses, for creative imagination, for theoretical ventures into the unseen world of physical reality which lies in back of the seen world that is mathematically described. For Petzoldt, such theories are works of art not of science.[39] Aliotta shares in these views.[40] Positivism has gained a strong foothold among both scientists and philosophers. It has a tremendous influence on the books and articles which philosophers in America have been publishing on both physics and philosophy. A nation like France has had a violent intellectual reaction against positivism under the impact of Bergson. Such a counter-movement has not yet begun in America. Here positivism still rules the field.

Positivism also reaches an extreme form in the so-called *Wiener Kreis* which wields great influence on present-day critics of science, as a review of contemporary books and periodicals amply bears

[37] *Cours de Philosophie Positiviste,* Paris, 1887, vol. 2, p. 312.
[38] *Kritik der reinen Erfahrung,* Leipzig, 1888, vol. 2, p. 352.
[39] *Einführung in die Philosophie der reinen Erfahrung,* Leipzig, 1900 (*passim*).
[40] Aliotta's philosophy is, however, a commingling of positivism, Kantianism, idealism, immanentism, and is not a doctrine of "pure experience."

witness. The doctrine of the Viennese school may be summed up in two principles: a) the physical sciences alone can attain valid knowledge of the real world; and b) the function of philosophy is an analysis of scientific concepts from the standpoint of logic with a view to clarifying their meaning.[41] Neurath views modern "scientism" as being antimetaphysical and empirical; it aims at a rigorous logic and at a mathematization of all the sciences.[42] Such are the characteristics of logical positivism as the movement has come to be known.

Logical positivism traces its origin back to Wittgenstein, who viewed all philosophy as a means of clarifying thought,[43] and to Bertrand Russell, who regards philosophy as logic.[44] It was developed by Wittgenstein's followers, chiefly Schlick and Carnap. Carnap, attempting to construct the concepts of all the empirical sciences by logical analysis, must, as Stebbing has shown, end in solipsism.[45]

For logical positivism, the meaning of a concept is its method of verification. The idea was advanced by Wittgenstein.[46] It undoubtedly expresses a truth that is interwoven in scientific method. It is because of the illicit transfer of this method to all fields of knowledge that logical positivism can find no place for philosophy except as logic and that Carnap's system, like the Cartesian doubt, must meet the fate of idealism and skepticism.[47] A sentence is

[41] Cf. Carnap, R., *The Logical Syntax of Language,* London, 1937, p. 279.
[42] *Le Développement du Cércle de Vienne et l'Avenir de l'Empirisme Logique,* Paris, 1935, p. 41.
[43] "Der Zweck der Philosophie ist die logische Klärung des Gedanken.
"Die Philosophie ist keine Lehre sondern eine Tätigkeit.
"Ein philosophisches Werk besteht wesentlich aus Erläuterungen.
"Des Resultat der Philosophie sind nicht 'philosophische Sätze' sondern das Klarwerden von Sätzen.
"Die Philosophie soll die Gedanken, sie sonst, gleichsam trüb und verschwommen sind klar machen und scharf abgrenzen," *Tractatus Logico-Philosophicus,* London, 1922, p. 76.
[44] "Philosophy, if what has been said is correct, becomes indistinguishable from logic," *Mysticism and Logic,* New York, 1918, pp. 111-112.
[45] *Logical Positivism and Analysis,* London, 1935 (*passim*).
[46] Cf. *supra,* n. 43.
[47] "In my opinion, Wittgenstein's conception of *verifiability* depends upon a serious equivocation with regard to the given, and hence, upon a muddle

meaningful only when it involves the rules by which it can be verified.[48] As Carnap says, the specification of an object consists in giving criteria of truth for those statements where the sign of the object occurs.[49]

The *Wiener Kreis* represents positivism in an extreme form, the death, so to speak, of the age of metaphysics in Comte's division of history and the complete absorption of philosophy by the positive sciences. It aims to unify all science on the basis of physics. It would make science itself a pointer-reading process like that prescribed by Avenarius and his school. "What is at all scientifically expressible," writes Neurath, "is no richer in fundamental relations than the symbols on a Morse tape which the telegrapher reads as they are sounded by his apparatus. In a sense, unified science is physics in its largest aspect, a tissue of laws expressing space-time linkages—let us call it: *Physicalism.*"[50]

Closely allied to the logical positivism of the Viennese School is the operationalism of Bridgman. Here, a concept is reduced to operations by which we measure. Bridgman writes, in describing his system, "In general, we mean by a concept nothing more than a set of operations; *the concept is synonymous with the corresponding set of operations.* If the concept is physical, as of length, the operations are actual physical operations; namely, those by which length is measured; or if the concept is mental, as of mathematical continuity, the operations are mental operations, namely those by which we determine whether a given aggregate of magnitudes is

with regard to the notion of *direct experience* and content, as these are understood by the Logical Positivists. *This table* is not *an experience* of mine. Hence, in saying 'I perceive this table,' I am *not* saying 'I perceive an experience of mine.' Hence, in the case when I do perceive this table, *this table* is indirectly *given.*" Stebbing, L. S., *op. cit.*, p. 28. In a similar way, Carnap, in his *Logische Aufbau der Welt*, is unable to establish an intelligible relation between his "knowledge by acquaintance" and "knowledge by description." Cf. Russell, B., *The Problems of Philosophy*, London, 1932, pp. 72-92.

[48] Schlick, M., *Sur le Fondement de la Connaissance*, Paris, 1935, p. 37.
[49] *Der Logische Aufbau der Welt*, Berlin, 1928, p. 222.
[50] "Physicalism," *The Monist*, vol. 41, p. 620.

continuous."[51] Statements which cannot be tested by operationalism, Bridgman refers to as verbalisms and therefore meaningless.[52] Only what is determined by space-time instrumental relations has "physical reality." Since the existence of an objective world cannot at present be operationally proved, he urges that the possibility of its non-existence should inspire physicists to "make more provision for such a possibility in our thinking."[53] Bridgman does not use the label positivist, but his system puts him definitely in the company of the modern thinkers who exalt the empirical method as the only tool of genuine knowledge. He is a positivist in his opposition to "the metaphysical taint."[54]

In appraisal of the foregoing opinions, it must be affirmed that as far as positivism seeks to eliminate the obtrusion of the metaphysical on the purely formal aspects of physics, it commends itself to a genuine philosophy of the sciences. But the errors of the system seem to be: a) an over-insistence on the purely mathematical, reportorial nature of physics; b) the opinion that the scientific method alone is a legitimate technique for study and that philosophy, if it is valid at all, has nothing to say about the real world but only about logical entities.

Physics cannot free itself from the concept of a *physical* reality whose quantitative attributes are reduced to methematical law. Meyerson, though sometimes inclined to exaggerate the ontal significance of science as opposed to its empirical formality, has

[51] Bridgman, P. W., *The Logic of Modern Physics*, p. 5; the author applies this view not only to empirical knowledge but to all cognition, *ibid.*, p. 32.
[52] Bridgman has attempted to exemplify his operationalism in *The Nature of Thermodynamics*. The reader may wonder, however, whether he has really carried it out to its logical conclusions. He admits, for example, in defining temperature, that "The starting point is the undoubted qualitative connection between the temperature concept and our crude physiological sensations of hot and cold," pp. 10-11. Quality as such is, however, not mensurable, and already, unless we misinterpret Bridgman's thought, we have the introduction of a non-operational element. Secondly, we may ask whether the physiological operations (sensations of hot and cold) constitute our temperature concept, according to Bridgman's canon, or whether the temperature concept is not the result of these operations. If this is true then operationalism fails.
[53] *The Nature of Thermodynamics*, p. 219.
[54] *Ibid.*, p. 216.

brought to the fore that physical science demands the concept of a reality, a thing.[55] "It is only when the locus of those measure-numbers is discovered in certain *qualitative* continuities, familiar enough in our daily activities that the predictive power of science becomes intelligible."[56] Physics is not only mathematics. It erects its mathematical laws upon a physical insight into an objective, physically existing world. If we trace back physico-mathematical theories, even those which are most highly mathematical, we find that in their origins they exact knowledge of phenomena in the real world which interact with one another and possess physical properties. Such theories demand also, in their application, insight into a physical situation. Even Bridgman has written, "Let anyone who maintains that there is nothing in nature except pointer-readings or coincidences engage to reproduce the situation that gave rise to the pointer-readings in terms only of the framework and the pointer-readings themselves."[57] Physics does not consist simply in an historical, reportorial account of mathematical properties. It demands vision, originality, intuition, discernment of causes, of new *physical* relations, visualizations of atoms, of electrons, of spin, and even—at least in an indirect way—of such supposedly unpicturable phenomena as space-curvature and wave-properties. It is only thus that the mathematical statements of modern physics can have physical sense and predict phenomena that we check with our senses in physical experiment. Otherwise we should become lost in a dim haze of mathematical symbols. Experiment would lose its meaning. Hypotheses are the work of keen minds which transcend reportorial observation in order to make their experiments intelligible. As Huxley has written, those "who refuse to go beyond facts rarely get as far as fact."[58] And Schroedinger has reached "the inevitable conclusion that we cannot close the door to the entry of subjective factors in determining our scientific policy and in giving a definite direction to our line of further advance."[59] Physics involves more than mere laws, mere declarations of fact.

[55] *De l'Explication dans les Sciences,* pp. 17-44; cf. *supra,* p. 8.
[56] Nagel, *op. cit.,* p. 74 (italics mine).
[57] *The Nature of Physical Theory,* Princeton, 1936.
[58] *Methods and Results,* New York, 1894, p. 62.
[59] *Op. cit.,* p. 87.

This is not to belittle the attempt of modern physics to purge itself of anthropomorphic elements. It is laudable to preserve the unity of the physicist's formal object.[60] But between anthropomorphism and a cosmic agnosticism of physical reality, there is the light of reasoning by analogy which genuine philosophy may submit to the modern physicist. Our ideas of force, of mass, of waves, and so on may not be projected into the exterior world exactly as we know them from our psycho-physical sensations. Yet they may have an analogical correspondent in the outer world. In opposing the so-called anthropomorphism of classical physics, contemporary scientists and philosophers are in danger of introducing an anthropomorphism of their own, based on the naive view of the world as a mere mathematical reality and a naive view of man as a completely passive observer.[61]

Positivism also goes to extremes in reducing all valid knowledge to that empaled by the scientific method. On this basis, scientific method, whether it be discussed in terms of logical positivism or operationalism, must be applied to establish its own validity. We are immediately caught in the contradiction of circular demonstration. The positivist opinion is based upon the unfounded belief that because the scientific method has achieved such great success in one field of knowledge it can qualify as the method of all valid learning. Positivism has swept on to its logical conclusion the doctrine long drifting through modern philosophy that the only reality is that of quantity and that the only knowledge is that of the senses.

Against this view, any genuine philosophy can reaffirm: a) the existence of a reality even in matter which is not mere quantity and which renders being intelligible—this is form; b) the existence in man of a supra-sensory, spiritual, intellectual power which can grasp this formal principle and which need not be governed, in its methods of knowing, by the quantitative methods of science. In fact, quantity as such does not make sense by itself. It is sheer

[60] ". . . so können wir kurz zusammenfassend sagen, die Signatur der ganzen bisherigen Entwicklung der theoretischen Physik ist eine Vereinheitlichung ihres Systems, welche erzielt ist durch eine gewisse Emanzipierung von der anthropomorphen Elementen, speziell den specifischen Sinnesempfindungen," Planck, M., *Wege zur Physikalischen Erkenntnis,* p. 5.
[61] Riezler, K., *op. cit.,* p. 73.

plurality of parts. Since, then, there are realities even in the material world which are higher than quantity; since man has powers of knowing in which the quantitative, scientific method is transcended, positivism as a cosmology, psychology, and theory of knowledge is incomplete. Positive science is complemented in its method of knowing by the method of philosophy and in its attitude toward phenomena by a philosophy of being.[62]

Logical positivism and operationalism much stand trial with positivism in general. Both may render a real service to physics in eliminating principles which are meaningless to the physico-mathematical structure of the science; in stressing clear definitions according to the physicist's canons of verification.[63] Secondly, though empirical physics must define its concepts in terms of methods of verification or in terms of operation, both logical positivism and operationalism have, if their systems are logically carried out, misconstrued the character of a concept and of definition which defines concepts. Both logically and psychologically, there must be a representation before empirical operations can be performed and scientific verifications carried out. Otherwise, knowledge is reduced to the sterile, senseless movement of operating on operations and of verifying verifications.

Psychologically this does not occur. Logically it would be an absurdity. We represent the *something* which is measured, verified, operated on. Without such awareness, there could be no science in the psychological sense.[64] As Planck has said, "The measurement gives no immediate results which have a meaning of their own."[65] In the psychological sense, we must therefore represent

[62] A detailed discussion of these two points lies much beyond the scope of the present work. The first question, the necessity of form, will be dealt with to some extent in the final chapter. For a defense of the second point, the reader is referred to Sheen, F. J., *The Philosophy of Science,* Milwaukee, 1934, *praesertim,* pp. 105-124; Rousselot, P., *L'Intellectualisme de Saint Thomas,* Paris, 1911; and Maritain, J., *Les Degrés du Savoir,* pp. 399-484.

[63] Maritain, J., "Science, Philosophy, and Faith," in *Science, Philosophy, and Religion: A Symposium,* New York, 1941, p. 170.

[64] "Unless one knew independently of the instrument what the instrument was designed to measure, it could never have been created," Benjamin, A. C., *An Introduction to the Philosophy of Science,* p. 116.

[65] *Where Is Science Going?* p. 95.

a *something* to be treated by the mathematical formality of mathematical physics.[66]

In the logical order, operationalism and logical positivism, if their premises are carried to the conclusion they suggest, do not conform to the rules of definition. They identify meaning with operation or with method of verification, in the last analysis. They leave no room, if their doctrines are followed to the letter, for anything but the circular process mentioned above—operating on operations. A logically sound definition based on measurement cannot be constructed without reference to what is being measured or verified, a reference that is grasped by intellectual insight, seeing "a whole that is articulated within itself."[67] Operationalism and logical positivism, considered as canons of verification in physics, must be grounded in a principle which is not mathematically, operationally, positivistically reducible. This principle in man grasps the ultimately non-quantitative but starkly real, objective, compelling relation between being and measurement. This is judgment, bridging the gulf between two ideas and binding them, by the reflective, bending-back of spirit on itself into a unity which is a polarized contrast to what physics treats, namely, quantity. We speak of things which are measured in this or that way; of things which are verified in this or that way. We grasp intellectually a relation which is, as a relation, not in the things but between them. The thing being measured is the genus and the particular measurement or verification forms the specific difference. Together they comprise a species. With such a restriction, logical positivism and operationalism are not only valid but highly desirable canons for the physicist. They insist that in defining the various objects of his study, he must because of the point of view (formal object) adopted by his science, define them in terms of measurement and verification.[68]

[66] As Bavink argues, against Carnap in particular, conceptualization (Begriffsbildung) and measurement (Messung) are not synonymous, *op. cit.,* pp. 218 ff.

[67] Cf. *supra,* p. 24.

[68] Stebbing writes: "We cannot clarify our thoughts by thinking about thinking, nor by thinking about logic. We have to think *about* what we *were* thinking about. . . . This investigation is not linguistic. We must first know

A corollary of fundamental importance may be drawn from the foregoing analysis. If intellectual insight, which is not mathematically reducible, should and does operate both in justifying the systems of operationalism and of logical positivism and in the actual use of the two systems, then it follows that there is a legitimate knowledge outside the empirical and the mathematical method used by physics. The scientific method cannot be, it is not in practice, the only tool of knowledge. There is a subject-matter in the material world which physics itself cannot grasp but which philosophy attains by intellectual analysis and synthesis. Once we have reached agreement on this point, we have come a long way toward the settlement of the disputed frontiers between physics and philosophy.

Law, it was seen, is an empirical generalization which expresses a relationship in the real world through the medium of mathematical functionality. With proper interpretations, Mach, Poincaré, and the positivists in general can find their place in a genuine, organic philosophy which recognizes that reality has many aspects and that the aspects studied by physics do not exhaust matter's knowability.

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what facts are the case before we can fruitfully employ analysis for the purpose of clarifying our thoughts about the world," *op. cit.*, p. 36. This statement is a telling one against the view that philosophy must confine itself to the domain of logic.

CHAPTER V

The Function of Theory

Physics aims to correlate phenomena. To achieve this end, it is necessary to discover the more fundamental properties that the phenomena have in common. We go beyond direct experience which, in itself, reveals to us differences in the phenomena more than their community. We employ the method of hypothesis, what Planck has called "the indispensable tool of every inductive investigation."[1]

Newton's often-quoted maxim, *Hypotheses non fingo,* does not in reality contradict Planck's view. It does not argue towards a pure empiricism in physics, any more than hypotheses indicate that the science is solely *a priori.* Newton was insistent on the empirical, inductive character of physics. But he did not overlook its hypothetical, deductive aspects. He perceived in principle and in practice that the two are parts of one procedure which is called the scientific method.

Newton's philosophy of method may be summarized in his own words: "But to derive two or three general principles of Motion from Phaenomena, and afterwards to tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discovered: And therefore I scruple not to propose the Principles of Motion above mention'd, they being of very general Extent and leave their Causes to be found out."[2] He conceived of scientific method as an analytico-synthetic movement which passes from particular effects to general causes,[3] then "explaining Phaenomena proceeding from

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[1] *Wege zur Physikalischen Erkenntnis,* p. 150.

[2] *Opticks,* London, 1931, Query 31, pp. 401-402; cf. Burke, H. R., "Sir Isaac Newton's Formal Conception of Scientific Method," *The New Scholasticism,* 10, 1936, pp. 93-115.

[3] *Op. cit.,* p. 404.

them and proving the Explanations."[4] Already we note that Newton's methodology is neither inductive nor deductive but a mixture of the two. As he writes in the *Principia,* "the whole burden of philosophy seems to consist in this—from the phenomena of motions to investigate the forces of nature and then from these forces to demonstrate the other phenomena."[5]

His four *Regulae Philosophandi* also stress the inductive character of scientific concepts. We are to confine our explanations to the fewest possible causes needed to explain appearances (the principle of economy); the same effects are to be attributed to the same causes; qualities which are found in all bodies studied in experiment and which do not admit of more or less, are to be taken as the universal properties of all bodies; propositions, attained by induction, are to be held as true until the contrary is proved, either by the refinement of measurements or by the discovery of exceptions.[6] In these rules Newton's logic seems to be almost purely inductive and empirical. Here he seems literally to carry out his belief that "hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy."[7]

But what did Newton mean by hypothesis? If we look to the way in which he arrived at his most noted contribution to physics, his principle of universal attraction among bodies—the law of gravitation as it is commonly called—we find him to be using hypothesis in the restricted sense which it assumes in the vocabulary of the modern physicist. Newton set out to find a gravitational attraction between bodies that would give rise by deduction to Kepler's third law: that the squares of the periods of revolution of the planets around the sun are proportional to the cubes of the radii of the respective orbits. Employing the equation for the centripetal force necessary to keep a planet moving in its orbit, Newton set this formula equal to his own formula that the attraction of sun and planet varied as the inverse xth power of their distance apart.

[4] *Ibid.,* p. 405.
[5] *Principia Mathematica Philosophiae Naturalis* (Eng. transl. by A. Motte, revised by F. Cajori), Berkeley, Cal., 1934, pp. xvii-xviii.
[6] *Ibid.,* pp. 398-400.
[7] *Ibid.,* p. 547.

Using Kepler's observations and solving for x, Newton discovered the law of inverse squares. But what he was using was what we now call a scientific hypothesis. He started out with the supposition that the *sun and the planet attracted each other* with a force proportional to the inverse xth power of the distance between them. After he discovered that his principle was checked experimentally by the comparison of the acceleration of the moon toward the earth with the acceleration of freely falling bodies at the earth's surface, he found that he could derive all three of Kepler's laws from his mathematical calculations. He then generalized his principle according to the third of his *Regulae Philosophandi.* Here also is a hypothetical element, the extrapolation of the so-called law of gravitation to include all bodies.[8]

De Morgan has summarized the above method in the following: "Newton, ready prepared with the mathematics of the subject, tried the fall of the moon towards the earth, away from her tangent, and found that, as compared with the fall of a stone, the law of the inverse square did not hold for the moon. He deduced the ellipse, he proceeded to deduce the effect of the disturbance of the sun upon the moon, upon the assumed theory of *universal* gravitation."[9]

The dictum *Hypotheses non fingo* does not propose a pure empiricism in scientific method. The author of it did not mean, it seems, to exclude genuine *scientific* hypotheses from research. What Newton rejected were hypotheses in the sense of mere unverifiable guesses or metaphysical speculations.[10] He wanted to keep empirical science empirical.[11] But he used hypotheses in the scientific meaning; "if he had put into practice his *Hypotheses non fingo* in the sense in which it has been taken, we would not possess the law

[8] Actually, Newton's law does not explain all gravitational phenomena, v.g., deviations in the path of the planet Mercury, and the theory of relativity is deemed a more universal principle than Newton's statement.
[9] For a summary of Newton's method cf. de Morgan, A., *A Budget of Paradoxes,* Chicago, 1915, vol. 1, p. 86; and Case, "Scientific Method as a Mental Operation," in *Lectures on the Method of Science,* ed. T. B. Strong, Oxford, 1906, p. 18.
[10] Stebbing, L. S., *A Modern Introduction to Logic,* p. 316.
[11] *Ibid.,* p. 315.

of universal gravitation."[12] Newton's principle is not a law in the sense of an empirical generalization but "is the fundamental hypothesis of the Newtonian theory of gravitation."[13] The founder of classical mechanics was thus a representative of scientific method, where a hypothesis is the "indispensable tool of every inductive investigation."

Hypotheses are suppositions to account for the data of experiment. A distinction might be made between hypothesis and theory on the grounds that the former is a simple conjecture which, when verified according to scientific canons, transforms into the latter. But we speak interchangeably of the quantum hypothesis or quantum theory, relativity hypothesis or relativity theory. A distinction might also be made on the basis of extension, hypothesis being directed to a particular fact or group of facts and theory being concerned with a whole class of phenomena.[14] In the former category would be included such suppositions as that of electron-spin; the Pauli exclusion-principle, and so on. But in practice no distinction is observed between the two concepts.

Divided according to matter, theories in physics are of two types: mechanical and mathematical.[15] Mechanical theories emphasize the physical suppositions made in order to account for experimental evidence. The atomic theory, the kinetic-molecular theory, the wave or corpuscular hypotheses of classical optics, and the electrodynamical theory developed by classical physics on the model of a hydrodynamical system—all these are so-called mechanical theories. Mathematical theories lay stress on numerical aspects of physical suppositions. As examples, we have Fourier's theory of heat-flow, Maxwell's electromagnetic theory, and in general the systems of quantum mechanics and of relativity theory (this latter hypothesis tries to geometrize reality). But the distinction between the two divisions is not as sharp as might seem at first glance. The mechanical theories were treated mathematically by classical physics, as classical statistics bear witness. The atomic theory was

[12] Naville, E., *op. cit.*, p. 199.
[13] Lindsay and Margenau, *op. cit.*, p. 23.
[14] Thus, Margenau, H., "The Problem of Physical Explanation," *The Monist*, vol. 39, pp. 343-4.
[15] Cf. Meyerson, E., *op. cit.*, p. 35; Bavink, B., *op. cit.*, p. 31.

projected by Dalton because of the striking mathematical relations shown in the laws of definite and of multiple proportions. On the other hand, the mathematical theories of contemporary physics derive ultimately from mechanical hypotheses. Their origin can be traced back to *physical* presuppositions. They depend for their application on the knowledge of a physical situation. Ultimately the difference between the two types of theory depends on where the emphasis is laid.

"Mathematical" theories are not laws. The physico-mathematical suppositions are designed to yield empirically observed laws by deduction. Though the derived conclusions may check with experimental evidence we cannot validate our suppositions unless we prove that they alone can account for the facts. The three statistical systems employed in modern physics make suppositions concerning the original distribution and interrelationships of the particles. From these postulates, deductions can be made which accord with experiment and form statistical laws. But we have not thereby validated our presuppositions as the only ones which could account for the facts. The Schroedinger equation, a mathematical theory of quantum mechanics, yields by deduction the generalizations of facts that we check experimentally. It is possible that a different mathematical supposition could likewise account for the laws empirically observed. While laws, derivatives of theories, are true because of direct experimental evidence, the theories themselves, even of the mathematical type, are only provisional.

Divided according to method, theories may be, as Rankine said, hypothetical or abstractive.[16] They are hypothetical when conceived prior to observed facts and tested by subsequent experiment. They are abstractive when drawn from the observed facts. This is somewhat akin to de Morgan's distinction between Bacon's method of using facts to construct theories and the method, actually practiced by scientists, of using facts to test theories.[17]

Actually, both methods are in vogue in modern physics. A true hypothesis is a combination of the two. Planck's quantum hypothesis arose by an abstractive procedure, to use Rankine's term.

[16] Rankine, W., *Miscellaneous Papers*, London, 1881, p. 210.
[17] *Op. cit.*, vol. 1, p. 88.

The wave theory of matter was advanced by de Broglie before having any immediate experimental evidence on which to work. Maxwell's electromagnetic theory of light was not verified until Hertz's experiments twenty years later. Yet no theory is completely *a priori* and suppositional and then later verified, as Whewell seemed to hold.[18] In a strict sense, it is always a "post-supposition," based on previous knowledge which it seeks to interpret.[19] In this sense, all theories are drawn from observational data. But once a theory has been conceived, its logical consequences are deduced and compared with experiment. Thus the facts are used to test the hypothesis which suggested them.[20] The theory which successfully interpreted the initial facts and predicts new ones is placed on a more solid footing.[21]

The empiricism of Bacon and Mill has been easier to describe in the classroom than to follow in the laboratory. Bacon left no room for hypotheses, for anticipations of nature. Mill admitted theories. But he misconceived their nature. A thorough-going empiricist, he viewed hypotheses as capable of becoming proven facts. He refused to regard as the truth-test of a theory its usefulness in "suggesting a line of investigation."[22] Here he is at variance with modern physics. His canons, because they leave no room for intellectual analysis and prescribe pure induction, are neither methods of discovery nor methods of proof. If we decide to let the facts speak for themselves, we can ask: what are the facts and which ones should we study?[23] The value of the Baconian method and of Mill's canons can be gauged by the fact that no scientist has ever used them. They are not methods of proof because their crudely empirical character does not permit the generalization of experimental fact which is a scientific law. If they are methods of discovery, then they pertain to the psychology of

[18] *A History of Scientific Ideas*, London, 1858, vol. 1, p. 29.
[19] d'Abro, A., *Evolution of Scientific Thought from Newton to Einstein*, p. 437.
[20] v. Hartman suggests that theories are intimated by facts to the mind of the physicist who then works backward to verify his ideas. *Philosophie des Unbewusstseins*, Berlin, 1874, p. 355; cf. also pp. 260-280.
[21] Case, T., *op. cit.*, p. 27; Naville, *op. cit.*, pp. 59-60.
[22] *A System of Logic*, London, 1895, p. 325.
[23] Cohen and Nagel, *op. cit.*, p. 201.

invention and not to demonstrative logic. In the strict sense, there are no rules for discovery, "the methods of investigation are many and lawless, whereas the methods of proof are one and law-abiding."[24] A discussion of the process of discovery, which is a psychological question, is at most of very indirect concern in appraising the logical significance of science. Psychologists themselves cannot give a satisfactory answer to the nature of genius, talent, the inventive activity of the mind which is involved in scientific discovery. Discovery is an art, not a science. "Francis Bacon, the official herald and announcer of the scientific method, totally misunderstood this quality in his charge. He imagined that the scientific method was itself as mechanical a thing as the picture of the universe which it produces by its efforts."[25] The scientist cannot explain his applied logic in passing from one premise to another and finally to a conclusion. He "proceeds largely by hunches and guesses, by trial and error, by intuition, by unconscious inferences and techniques based primarily on habit. The point is not that these are bad methods but that they are accepted uncritically."[26]

Demonstrative proof presupposes abstraction. It is based ultimately on propositions that are self-evident.[27] The predicate is seen to be contained within the subject by an act of apprehension.[28] Strict demonstration may therefore be said to proceed from a knowledge of essences in which the middle term is predicated of the minor and the major is predicated of the middle.[29]

Scientific method, measuring as it does only the metrical aspects of the material world, is closed off from a knowledge of essences. But it seeks admission to that world at a lower level. It has in fact proposed a substitute deductive system of its own—the method of hypothesis. A theory is "the practical equivalent of essence."[30] With this as a base, the scientist sets out to deduce "attributes."

There is a methodological parallel also in the scientist's process

[24] Dubs, H., *Rational Induction*, Chicago, 1930, p. viii.
[25] Needham, J., *op. cit.*, p. 81.
[26] Benjamin, A. C., *An Introduction to the Philosophy of Science*, p. 30.
[27] *In I Anal. Post.* 3.
[28] *Ibid.*, 1.
[29] Joseph, H., *An Introduction to Logic*, Oxford, 1916, pp. 308-309.
[30] Maritain, J., *op. cit.*, p. 67.

of arriving at a theory and the philosopher's apprehension of form. Though a theory may be suggested by facts of science and though a knowledge of essence may be derived from philosophical facts, in a genuine sense both are abstractions.[31] Both seek to provide a basis for facts observed, the philosopher in the world of rational necessity, the scientist in the world of theories. Scientific method is often referred to as inductive. But induction is only a step in the procedure of physics. The ladder is many-runged. To explain observed facts in the quantified world, it remains in the world of quantity and seeks quantified antecedents in time and in nature which account for the facts.[32] We deduce the effects from hypothetical causes. In philosophy, however, causes and essences are not supposed. They are abstracted by intellectual analysis of the data of sense. The result is not a mere seizure of quantified antecedents (either mechanical or mathematical). It is the grasp of intelligible form.

Accordingly, one of the fundamental marks of a hypothesis is that it permit deductions to be made from it. The wider the scope of the theory, the more firmly it is established. This is so because the more universal his hypothesis the more deeply the physicist seems to probe into the intimate and ultimate structure of the world of quantity—his substitute for the philosopher's concept of essence.[33] "Hypotheses are valuable for science," write Cohen and Nagel, "in proportion as they permit an organized deduction of consequences which are applicable to domains qualitatively different."[34]

Maxwell's theory united electromagnetism and optics. Quantum theory has been of far-reaching significance for modern physics because it has united the study of material particles and of radiation which, in the classical system, were considered as two separate and

[31] Naville, E., *op. cit.*, p. 208; Whitehead, A., *Principles of Natural Knowledge*, p. 108; Needham, J., *op. cit.*, p. 82; Westaway, F., *Science and Theology*, London, 1920, p. 252; Eddington, A., *The Philosophy of Physical Science*, p. 55; Planck, M., *Where Is Science Going?* pp. 86-87; Duhem, P., *op. cit.*, p. 77; Maritain, J., *op. cit.*, p. 49 note.

[32] Becher, E., *op. cit.*, p. 15.

[33] Ritchie, *op. cit.*, p. 59.

[34] *Op. cit.*, p. 283.

irreducible domains. A similar unifying purpose was served by Einstein's general theory of relativity. Newton had already generalized Kepler's laws of planetary motion into the principle of gravitation which laid the groundwork for a universal mechanics. Einstein generalized Newton's "law" itself. The synthesizing theory of relativity aims to combine gravitational, electrical, and magnetic phenomena into the all-embracing concept of the field theory in which matter and energy are equivalent. Quantum mechanics and relativity theory on the level of science thus strive after something more fundamental in nature than the bifurcated theories of classical physics.[35] The quantum and relativity theories thus provide a more remote aspect of essence in its substitute form. From these hypotheses, a greater number of deductions can be made than under the disparate theories of classical physics.[36] "Our experience up to date," says Einstein, "justifies us in feeling sure that in Nature is actualized the ideal of mathematical simplicity."[37] This is only a modern paraphrase of Laplace's belief that in classical mechanics all motion could be reduced to a single mathematical equation. The aim of physics then is to attain the most fundamental mathematical relation, the most fundamental schema, the most remote quantities in the make-up of matter, from which all other facts can be deduced.[38]

In a sense, a theory never really dies in the history of science. It is merely corrected and transformed. Bohr did not abolish the Rutherford atom-model. He merely corrected it. The two-fluid theory of electricity has reappeared in the form of the electronic theory of positive and negative charges. The theory of photons did not abolish the wave-theory of light. It built a new system in

[35] Planck, M., *Physikalische Rundblicke*, Leipzig, 1922, p. 121; also, by the same author, *The Universe in the Light of Modern Physics*, London, 1921, p. 21.

[36] Dotterer, R., *Philosophy by Way of the Sciences*, p. 283; Lenzen, V. F., *The Nature of Physical Theory*, New York, 1931, p. 47.

[37] *On the Method of Theoretical Physics*, New York, 1933, p. 15.

[38] "An ideal shines in front of us, far ahead perhaps but irresistible, that the whole of our knowledge of the physical world may be unified into a single science which may be expressed in terms of geometrical or quasi-geometrical conceptions," Eddington, A., *The Nature of the Physical World*, p. 136.

which the undulatory hypothesis was included. Still less does the Einsteinian concept of gravitation, in ordinary space, abolish the Newtonian one. The reason for this is not far to seek. If the old theories were able to account for phenomena, their content must be embodied somehow in the new hypotheses that take their places.[39] Einstein writes that since the special theory of relativity grew out of the Maxwell-Lorentz account of electromagnetic phenomena, the arguments that support the latter also support the former.[40] This merely confirms the opinion above that science seeks by hypothesis after the most fundamental metrical character of matter. From it physics seeks to deduce all else.

The important function of deduction in the procedure of modern physics cannot ratify the description of scientific method as a purely inductive process. Bacon, Mill, Hume, and Herschel were not the philosophers of science, either from the philosophical point of view which rejects their methods on principle or from the scientific standpoint which rejects their method in practice. The method of modern physics is a mixed method which begins in experience, transcends experience to account for it, and after a deductive development of its abstracted suppositions through mathematical and logical inference, returns to experience to test its account and to gather fresh material for a repetition of the cycle.[41] Smart "looks upon induction and deduction not as two separate methods or techniques, but as two inseparable aspects of that process of reasoning which has as its main task the progressive deepening and extending of the knowledge we already possess."[42] Even in the statistical domain of modern physics, we find both inductive and deductive processes. Statistics is not a mere enumeration. Its actual development has resulted largely from a process of deductive reasoning.[43] The fundamental assumptions of quantum statistics are the hypotheses of equal *a priori* probabilities and of random a priori phases for quantum states. Though these assumptions are not amenable to direct testing, the mathematical laws to

[39] Benjamin, A. C., *The Logical Structure of Science*, p. 224.
[40] *Relativity*, p. 58.
[41] Case, T., *op. cit.*, pp. 23-24.
[42] Smart, H. R., *The Logic of Science*, New York, 1931, p. 43.
[43] Tolman, R., *op. cit.*, p. 4.

which they give rise have been found to agree with experiment. The original assumptions have been validated for the scientist by the derived conclusions.

But if physics is not completely inductive, neither is it a completely deductive system. Hence, Descartes' logic has been modified by the historical direction of the science he helped to found.[44] Physics is not completely deductive, *a priori*. It must begin in the external world. It must return to it. If the facts do not fit the theories, it is the theories that must go, not the facts. The facts come first in the order of knowing; the theory is first in the order of being, hypothetically so in the sense discussed above.[45] If indeed theories precede facts according to de Morgan's dictum, this is only because the theories themselves have been constructed on a knowledge of previous facts. Deduction thus becomes in a sense a *via inventionis*. It reaches farther than pure induction and gives it birth. It is creative of new knowledge.[46] If a theory is true, then certain facts can be predicted from it. The prediction of phenomena, which physicists proclaim to be the sole purpose of a theory, constitutes the verification of the supposition.

Verification is a process of mensuration and observation to check the deductions from hypotheses. In direct opposition to Bacon's views, the modern physicist does not believe that he can interpret nature unless he can first anticipate her; nor that he has obeyed nature, unless he has first commanded her. Against Mill, he finds the great value of his theories in their ability to suggest new lines of investigation. He reverses Mill's suggestion of ascribing assumed laws to known causes. He does not follow the pure induction of the five canons. Herzfield's statement may be repeated here: "Understanding of a phenomenon means that we can reduce a large number of complex phenomena to a few simple principles which might enable us to predict ahead of time what will happen under given conditions in the future."[47]

[44] Gilson, *Etude sur le Rôle de la Pensée Médiévale dans la Formation du Système Cartésien*, p. 180.
[45] Cf. *supra*, pp. 2 ff.
[46] Heisenberg, W., *op. cit.*, p. 17.
[47] "The Frontiers of Modern Physics and Philosophy," *Proc. Amer. Cath. Phil. Assoc.*, 1930, p. 40.

Verification is a return to the data of sense from the universe of reasoning. If the theory can forecast what data should occur in experiment, it is said to be verified. De Broglie's hypothesis of matter-waves predicted the results of the Davisson-Germer experiment which was conducted sometime later. The prediction was a potent argument in favor of the theory. The hypothesis of general relativity was placed on a far solider basis through the deflection of light observed during the solar eclipse of May 29, 1919 by the Joint Committee of the Royal and Royal Astronomical Societies. If physics is a study of matter as metrical, the chief function of theory is to serve as a guide to new experiments, new measurements, new metrical data.[48]

This predictive function of a theory is constantly emphasized by the scientists in their literature. The majority of the leading physicists seem agreed that their purpose is not to probe into the ontology of matter. It is merely to predict the results of experiment. Thus Dirac writes: "The only object of theoretical physics is to calculate results that can be compared with experiment."[49]

The Newtonian concept of gravitation was once accepted as a working principle: but Einstein's law of gravitation was better able to predict phenomena in stellar space. Newton's principle was called into question as a universal law. The undulatory theory of light was accepted by the 19th century because it was able to explain interference and diffraction-bands; but it was unable to predict all the facts concerning light, for example the photoelectric effect. Hence, the particle theory was revived. Considering light as both a particle and a wave, physicists have been able to predict phenomena verifiable by experiment. Until the day when the existing theory fails in its forecasting, physics will continue to employ it as a sound working principle.

The emphasis on theory as a mere instrument to predict the results of experiments has tended to the opinion that theoretical physics has nothing to say about the structure of the real, is concerned only with the forecasting of *laboratory* data. Dingler, for instance, writes that theoretical physics does not concern the real.

[48] Dingler, H., *op. cit.*, p. 175.

[49] Cited by Ruark and Urey, *Atoms, Molecules, and Quanta*, New York, 1933, p. 219.

Its purpose is a practical one and has been successfully tested. So long, he says, as theoretical physics stimulates experimental physics to new empirical findings, it has justified itself.[50] It has no connection with reality. This is the view of the idealist and positivist mentality. Against it, it must be affirmed that experiment and reality are not two different worlds. Though reality may be altered, sometimes in a radical way, by the very act of experiment and by its isolating character, the matter and energy involved are still integral parts of the quantified world to which nothing has been added or taken away. Even Bergson, who attacked science as an artifact, recognized that experiment was not completely artificial and arbitrary.[51]

Art does not add to the material constants of nature. It recombines them in new ways. An experiment is an event in the real world. It is real itself. If it is artificial, in the common meaning of that word, it is none the less natural in its efficient and material causes which are the only etiology which physics knows. A theory in physics not only predicts the results of experiments. It predicts real events. Though experiment may interfere with nature, it does not destroy or even diminish it. We may by proper corrections, argue back to a more or less exact knowledge of nature itself. Theories are projected to render experiments intelligible. Experiments, however, are part of reality. Even interference conveys important evidence concerning the object which is studied and which behaves in this or that way under alteration.[52]

The predictive function of theory as conceived by the contemporary physicist confirms the view that method in physics is a movement toward the deduction of facts from the substitute concept of essence (on the level of quantity) which is the middle term of scientific proof. As Plato and Aristotle noted, science is of universals. Universals are general truths because they are independent of time and space, which are the factors of change. The fact that physics seeks after principles that hold at various times and various places indicates that it is seeking after those fundamental, universal metrical characteristics of its metrical subject-matter.

[50] *Op. cit.*, pp. 37-38.

[51] *L'Evolution Créatrice*, p. 108.

[52] Benjamin, A. C., *An Introduction to the Philosophy of Science*, p. 105.

Such characteristics vindicate the scientific nature of physics itself, at least its tendency to be a science. Without unchanging, universal principles, there could be no science. Physics seeks order in the world. This quest is a struggle after the unifying notes which reduce into a system the multiplicity that our senses find in matter. If there were only individuals in the world, everything would be unique. There could be no comparative judgments. These acts of the mind are required to discover general relations among phenomena and thus to construct science. Positivism to the contrary, it is obvious that abstraction—the act by which the mind arrests quiddity or essence (in the wide sense of the words)—is an integral part of scientific method. It is only by this mental apprehension that we can rise above the mobile, existential world of sense cognition and grasp those characters of experience which are not peculiar to the passing moment. Such characters lie in the region of the universals where any science must make its home.

It is by no means an accident, then, in physics, which is a science, that the aim of theory should be the prediction of new phenomena and that verification should be only the test of its ability as a forecaster. If a theory is successful in its predictions, it is said to be verified. The ultimate significance of this attitude toward verification is that independence of time, place, and the accidental variations, introduced by the experimenter to determine more precisely the functionality involved, is in itself evidence that the theory reaches invariants, essential characteristics (as far as physics goes) of the material studied. It is these characteristics which enable the physicist to make general statements.

The world of theory is still hypothetical, even in its own order of quantified being *qua* quantified. This imposes obvious provisions on the general statements themselves. "Consequently," writes Nagel, "while every instance of the application of the theory is a test of the theory, the theory is formulated for *possible* as well as actual cases, and is not, therefore, completely verified in the latter."[53]

The theory is a working hypothesis which guides the scientist in his experiment. It can be modified whenever facts warrant,

[53] *Op. cit.*, p. 57.

precisely because of its hypothetical nature. In this sense, the world of theory is more a seeking than a finding, more a *tool* in Dewey's vocabulary,[54] than an ultimate end which is good in itself because it is true knowledge. Yet the representative character of a theory is not absent. For this reason, as we saw, theories are never completely abandoned. They are only revised and re-interpreted. The very fact that a theory can predict future phenomena proves that it has in some way represented the real world.[55] Maritain's distinction between the progress of science as *extensional* movement and that of philosophy as an *intension* or deepening of knowledge is appropriate.[56] Physics moves along the surface of the real. The wreckage of its old ideas scattered over its path is ample testimony to the fact that it is always seeking, seeking indeed to disprove its own hypotheses and find new ones which will, like their predecessors, be only provisionally entertained. As Lichtenberg has asserted, truth is the asymptote of research. Philosophy, on the other hand, moves downward and inward through the ontal structure of matter. It is still seeking and always will be; for the ultimate answers to man's questions will be found only in the pure being which is the God of traditional philosophy. But its search is on a different level where the ultimate answers have in some measure been found. Philosophical progress consists in exploring the ultimates by a deeper and deeper penetration. The empirical physics of Aristotle has long been abandoned. His philosophical physics (cosmology) has survived—a testimony of its contact with the real and not merely hypothetical world of causes and reasons where the spirit of man may enter.

The nature of hypothesis has now been defined sufficiently for present purposes. Theory has been located within the logical framework of physics. Having seen the relation of theory to physics, we may now probe further into the relation of theory to reality.

[54] "Logical ideas are like keys that are shaped with reference to the opening of a lock," *How We Think*, New York, 1933, p. 134.

[55] Duhem, *op. cit.*, p. 41.

[56] *Les Sept Leçons sur l'Etre*, Paris, pp. 6 ff.

CHAPTER VI

The Significance of Theory

If hypotheses are provisional, when do they become true?

Actually, forward-looking physicists do not attempt to transfer their physical speculations to the world of being as an absolute explanation. Contemporary physicists regard the so-called mechanical theories as anthropomorphic. They refuse to trace mathematical hypotheses to picturable counterparts in the real. The purpose of a theory is to predict, not to explain or picture. When it can no longer forecast the future, it will be amended accordingly. As a theory, then, it is never considered to be true in the genuine sense of the word. Though it is said to be verified by its prediction, this verification is no inexorable conformity of intellect and reality. "If the new facts agree with the theory," Herzfeld writes, "that does not give *logical* proof for it; that would only be the case if there existed two alternatives."[1]

This provisional acceptance of hypotheses was noted by Aquinas. He laid down principles of method on this point which provide rich material for a critical study of modern physics. An insufficient way of explaining a phenomenon, he writes, is to posit a cause that is merely *consistent* with the effect in question. This, as he added, was the case in the astronomical system of his day in its theory of eccentrics and epicycles.[2] But this method of explaining, Aquinas adds, is not sufficient for true proof. It is possible that the observed facts can be accounted for by a different hypothesis.[3]

[1] "The Role of Theory in Modern Physics," *The New Scholasticism*, 8 (1934), p. 320.

[2] Duhem remarks that in the Aristotelian astronomy of homocentric spheres, we discern a genuine example of scientific method as it is practiced today and a genuine case of scientific theory. Beginning with a number of simple geometrical principles, deductions are made to explain observed data, *Le Système du Monde*, Paris, 1913-1917, vol. 1, p. 128.

[3] "Ad aliquam rem dupliciter inducitur ratio. Uno modo ad probandum sufficienter aliquam radicem. . . . Alio modo inducitur ratio non quae sufficienter probat radicem, sed quae radici iam positae ostendat congruere consequentes effectus; sicut in astrologia ponitur ratio excentricorum et epicyclorum, ex hoc quod, hac positione facta, possunt salvari apparentia sensibilia circa motus caelestes: non tamen ratio haec sufficienter probans, quia etiam forte alia positione facta salvari possent," I, 32, 1 and 2.

We cannot say that the theory which we have conceived is the only one which can "save the facts" in question.[4]

The definition of truth as the conformity of intellect and reality is the traditional correspondence-doctrine. If physics does not claim such conformity for its theories, as Herzfeld and others declare, it nevertheless has its own criterion. From an inspection of the science itself, it would seem that this criterion is coherence. Aquinas suggests this fact in stating that a hypothetical explanation "shows that the effects deduced are congruous with an already posed principle."[5] The antecedent need only be consistent with the effect. It need not be its true cause.

The coherence doctrine of truth is the legacy of Hegel. It has been applied by its advocates to the whole of knowledge. "Truth in its essential nature," says Joachim, "is that systematic coherence which is the character of a significant whole."[6] And F. H. Bradley writes: "Thought essentially consists in the separation of the 'what' from the 'that.' It may be said to accept this dissolution as its effective principle. Thus it renounces all attempt to *make* fact, and it confines itself to content. But by embracing this separation, and by urging this independent development to its extreme, thought indirectly endeavors to restore the broken whole."[7] The function of knowledge is to systematize.[8] Truth consists in an "arrangement of ideas, self-consistent and complete."[9] Contradiction indicates that we have not found this harmonious system. We must redistribute the discrepancies "in a wider arrangement."[10] In

[4] "Licet enim talibus suppositionibus facta appareant salvari, non tamen oportet dicere has suppositiones esse veras, quia forte secundum aliquem modum nondum ab hominibus comprehensum apparentia circa stellas salvantur," *In De Coelo et Mundo*, II, 17.

[5] *The Nature of Truth*, Oxford, 1939, p. 76.

[6] *Appearance and Reality*, London, 1893, p. 360.

[7] Joachim, *op. cit.*, p. 69.

[8] Bradley, *op. cit.*, p. 360.

[9] *Ibid.*, p. 303.

Joachim's judgment, scientific statements take their meaning from their place in the system.[10]

As in the case of physical science, knowledge is always seeking, never finding, pausing in its path, but never attaining its goals. "Truth," says Bradley, "is the predication of such content as, when predicated, is harmonious, and removed inconsistency and with it unrest. But because the given reality is never consistent, thought is compelled to take the road of indefinite expansion."[11]

Though profoundly thought through and beautifully written, Bradley's philosophy, neither at its origin nor in its development, admits of contact with being. In a genuinely Platonic sense, thought, for Bradley, comes to grips with only the *whatness* of things. It does not grasp, as realism compels, *existent* essences, i.e. essences with reference to existence. For Bradley, the mind stretches out toward a "self-consistent, all-inclusive" system of content. For a realist, like Aquinas, since the mind is measured by its object, truth is a relation between the intellect and that which *is*. A genuine philosophy does not dwarf itself to a sheer knowledge of essences or "content." Not that which is thinkable is true but that which *is*, and the mind lays hold of truth, elaborates a system of knowledge, only in so far as it brings itself into conformity with this being that is.

The coherence doctrine of truth is not without its commendation. What is disastrous is to take it as the definition of truth itself. Consistency, though not the essence of logical truth, is its consequence. When our thought contradicts itself, we are sure that we have not yet brought our minds and being into conformity. Being is not self-contradictory. So inconsistency in thought goads us onward to "get at the truth." In inductive mathematics, the coherence doctrine is fundamental since the law of contradiction is the only law that holds in this domain. Hence, there can be, for instance, any kind of non-Euclidian geometry alongside the Euclidian one so long as it is not contradictory in itself. Lastly, the coherence doctrine of truth applies as a formal standard of physical theories, *qua* theories. When Aquinas talked about the congruity of cause

[10] *Op. cit.*, p. 95 and p. 102.
[11] *Op. cit.*, p. 165.

and effect in physical science, he was using a synonym for "coherence."

A theory does not probe down to existent causes. It seeks after content, what a thing is, without reaching fact, whether it is. Physics finds a cause that is consistent with the effects and then weaves this concept into the "self-consistent, all-inclusive whole." To see this, one has only to take the pulse of modern physics. In nineteenth-century physics, the corpuscular and undulatory theories of light were opposed. Quantum theory has made the two cohere by redistributing the "discrepancies into wider arrangement,"[12] Anomalies in the classical theory of measuring motion were transcended by the theory of relativity. Classical theory was not abandoned when quantum and relativity mechanics arrived. According to the Bohr correspondence principle, quantum theory becomes identical with classical physics when the energy involved in a problem is great enough. Likewise, relativity mechanics comes into play only when velocities approach that of light. Classical physics was not thrown out. It was restricted to a special case of other systems as physics, expanding its knowledge, entered the domains outside ordinary space. Such other systems, quantum and relativity mechanics, were discovered to be more inclusive,[13] more self-consistent, more unitary in system than classical physics which is now confined to ordinary space. When present-day theories no longer meet these demands, new ones will be projected that will be more consistent with observed data and that will "save the phenomena." We see here why theories, once well-tested, are never completely supplanted by new ones. Their content is incorporated in some way with the new system which is more coherent with experimental effects.[14] Though genuine philosophy cannot apply the coherence theory of truth to the whole of knowledge, it can nevertheless find room for such a doctrine in formally qualifying sci-

[12] Cf. *infra*, p. 163.
[13] "The test which I advocate is that of a whole of knowledge as wide and as consistent as may be. In speaking of system, I mean the union of these two aspects, and this is the sense and the only sense in which I am defending coherence," Bradley, F. H., *Essays on Truth and Reality*, London, 1914, p. 202.
[14] Weyl, H., *Mind and Nature*, Philadelphia, 1934, p. 46.

entific hypotheses. Their purpose is not truly to explain in the full and formal sense of the word. It is only to "save the phenomena."

The pragmatic theory of truth plays a role in physics as a test. Theories aim to predict phenomena, and "the truth or falsity of an idea and the question of whether it has definite meaning is relatively unimportant: what matters is that it shall give rise to useful work."[15] If one theory is able to predict observable data where others fail, it is accepted, according to scientific canons, as being in accord with the facts. The doctrine of judging truth by its practical consequences developed in America in the pragmatism of Peirce and James and in the instrumentalism of Dewey. Like the coherence doctrine, it was extended to the whole of knowledge. This was a false generalization. It overlooked the distinction between the useful and the good in itself, between the absolute reality which must be served and the relative reality that must serve it. But like the doctrine of coherence, pragmatism has a licit field of operation in the logic of scientific theory.

"The full reality of truth," James wrote, ". . . is always some process of verification, in which the abstract property of connecting ideas with objects is workingly embodied."[16] James insisted that an idea must work. Like a scientific theory, it must work in the concrete, directed toward definite objects.[17] "My thesis is that knowing here is *made* by the ambulation through the intervening experiences. If the idea led us nowhere, or *from* the object instead of towards it, could we talk at all of its having any cognitive quality."[18]

Dewey is closer to the scientific method by his own words. He declares that "scientific method is the only authentic means at our command for getting at the significance of our every day experiences in the world in which we live. It means that scientific method provides a working pattern of the way in which and the conditions under which experiences are used to lead ever onward and

[15] Planck, M., *The Philosophy of Physics,* New York, 1936, p. 106.
[16] James, W., *The Meaning of Truth,* New York, 1910, pp. 202-203.
[17] "The trueness of an idea must mean *something definite in it that determines its tendency to work* and indeed towards this object rather than towards that," *ibid.,* p. 174.
[18] *Ibid.,* p. 141.

outward."[19] Knowledge is an instrument, the value of which is to be gauged by the work it performs. It must relate to concrete experiences. Its worth is determined entirely by its practical results.

Though the philosophy of pragmatism has not survived the attacks of its critics and though the pragmatic method cannot be extended to the whole of knowledge, it is the legitimate—indeed the only final test of a theory in physics. Such a test, agreement with experiment, must necessarily be a *practical* matter. Newton tested his principle of universal gravitation by comparing the phenomenon of a falling stone with the concrete behavior of the moon. Hertz confirmed Maxwell's views on the electromagnetic character of light by an indirect measurement of the waves shown to be propagated by his oscillator. In short, physics is an empirical science. Its viewpoints can include only those realities which have a practical, empirical meaning. Ideas that do not have practical, empirical, mensurable consequences are meaningless in physics. In speaking of physics, it can be affirmed with Margenau: "Constructs possess no generic properties which make them good or bad, acceptable or inacceptable; they derive their validity entirely from the success they achieve in providing satisfactory physical explanations. In the sense, then, that validity and hence reality depends on *function,* my view is essentially pragmatic."[20] Theories have meaning only in their reference to the practical experiments which they predict and account for.[21] The objection to the pragmatic theory of truth lies in extending it to the whole knowledge, where practical importance is an effect of truth, not its cause and criterion. In the scope of physics, pragmatism is a legitimate test

[19] *Experience and Education,* New York, 1938, pp. 111-112.
[20] Margenau, H., "Metaphysical Elements in Physics," *Reviews of Modern Physics,* 1941, p. 184.
[21] Restricting our statements to physical science, we may say with Dewey that "ideas or hypotheses are tested by the consequences which they produce when they are acted upon. This fact means that the consequences of action must be carefully and discriminately observed. Activity that is not checked by observation of what follows from it may be temporarily enjoyed. But intellectually it leads nowhere. It does not provide knowledge about the situations in which action occurs nor does it lead to clarification and expansion of ideas," *op. cit.,* p. 110; cf. also *The Quest for Certainty,* New York, 1929, p. 109.

of theories. The practical success of a theory, as observed in its prediction of experimental data, indicates that physics has reached an antecedent which is consistent with the effects.[22]

Traditional philosophy holds that operation is consequent on being and that as the operation is, so is the nature. Interpreted in their modern setting, these maxims hold the key to the philosophical interpretation of the pragmatic test as applied to scientific theory. All being is active, for all being possesses form and obeys finality. The activities of a being are measured by its own nature which is their source. Being is not static, inert, completely passive. It is informed, hence active; it is finalized, hence purposeful and dynamic. If the operations of a being are proportioned to its nature which is their ultimate material and formal cause, we can, by a study of a nature's activity, come to a knowledge of the nature itself. It was such a thought which led Aquinas to affirm that since we cannot know the essences of sensible realities as they are in themselves, we can know them in an indirect way by their effects.[23]

On the level of physics, the data predicted by a theory yield a knowledge of the nature of the hypothetical antecedent. It asserts its superiority over others which are unsuccessful in predicting the facts. We know it by its works. We accept it for its practical success. It is tested by empirical means. It has sense for physics only in so far as it has reference to the empirical. Scientific theories may be formally judged by coherence. Their test and sign of truth is pragmatic. Because a theory is shown to fit the facts by its function, it has in some way represented these antecedents. The laboratory data demand proportionate causes which we can know, empirically, only from the data themselves. An hypothesis, it must be said, has somehow entered into contact with the antecedents of observed data when it is a reliable forecaster of the data themselves. *Operari sequitur esse*. Only by an empirical test can an empirical science live up to its forename, empirical.

But if physical theory is based formally on the coherence doctrine of truth and is checked by the pragmatic test, it is not wholly out of correspondence with the real world. Since it is able to predict phenomena, it has somehow entered into contact with the real antecedents which determine the phenomena to be what they are. Its compatibility with the facts has been tested in practice. It corresponds to reality in its own way. When a theory is abandoned, the new theory, as was already noted, must include those elements which enabled the old one to account for the facts.

In the nineteenth century, it was fashionable to construct models to represent the mechanical structure of the world. "I never satisfy myself," Lord Kelvin said, "until I can make a mechanical model of a thing."[24] Today, however, physicists proclaim that we must abandon models, put our faith in mathematical equations alone. "If a picture exists," says Dirac, "so much the better; but whether a picture exists or not is a matter of only secondary importance. In the case of atomic phenomena no picture can be expected to exist in the usual sense of the word 'picture,' by which is meant a model functioning essentially on classical lines."[25] The mechanical explanation of matter has, it has often been said, been abandoned by contemporary physics. The theories of quantum mechanics and of relativity have come to replace them.

But the word *mechanical* is used in a very narrow sense by the contemporary physicist who now applies it only to classical physics which claimed, as Laplace affirmed, to give a precise prediction of the subsequent state of a system from a knowledge of its previous state.[26] Physics is still mechanistic, in the broad sense of the word. It seeks to interpret reality entirely in terms of its component parts. Whether we are successful in measuring the

[22] "Nous ne prétendous en aucune façon que pour une telle science la réussite *utilitaire* se substitue à la vérité, ce serait là à notre avis une conception barbare. Comme toute science, elle n'existe que pour être vraie," Maritain, J., *Les Degrés du Savoir*, p. 122.

[23] *De Ente et Essentia*, C. 5.

[24] Eddington wrote: "The man who could make gravitation out of cogwheels would have been a hero in the Victorian age," *The Nature of the Physical World*, p. 209.

[25] *The Principles of Quantum Mechanics*, Oxford, 1935, p. 10.

[26] *Mechanics*, as used by the physicist, has many English meanings. It can mean the study of machines as well as the study of masses in motion. In the latter sense, it is not synonymous with "physics" but is a branch of physics. *Mechanical* has also been used to describe the order of nature or, as the physicist puts it, causation—the relationship obtaining between two phenomena which enables us to predict one from our knowledge of the other.

realities or not does not modify our conception of the subject-matter as purely partitive. We may have classical, relativity, or quantum mechanics. We still have mechanism which, as Needham has shown, is a methodological necessity of empirical science.[27] "Indeed," according to Dantzig "the latest development in physics may be interpreted as the final triumph of the mechanistic tendency."[28] Physics, as we shall later see, atomizes matter. It is mechanistic by its very method. Whether we are able to represent the measured phenomena in a precise picture like the Rutherford atom-model is another question. The phenomena are still theoretically picturable.[29] The formal character of physics is mathematical. In so far as mathematics treats wholes as sums of component parts, physics is still mechanistic.[30]

But the mechanical nature of physics consists in more than mathematical equations. Models, images, and ideas are still formed and used by physicists. If, according to reliable psychology, there is no intellectual thought without concomitant images, the physicist cannot escape into a world of pure mathematical abstraction. Physics is a physical science. "It is necessary to know to what the assertions of a scientific theory refer, and a physical concept is therefore required which defines the subject-matter of the science."[31] Images provide a check for the development of our mathematics with a view to applying them to a physical situation. It is physical discernment which determines what mathematics should

[27] Cf. *supra*, p. 11 ff.

[28] *Aspects of Science*, p. 227.

[29] In this connection, Maritain has well pointed out that philosophy and contemporary physics both begin in the visible world and proceed to an unpicturable one. But the quantum world is still theoretically visible. It is only privately unpicturable because of our lack of experimental finesse. The noetic world of the philosopher is invisible in its very nature, i.e., negatively unpicturable, *op. cit.*, pp. 94-95.

[30] "Les équations se sont transformées, les grandeurs sont différentes, les méthodes ne peuvent pas être restées les mêmes; mais le thème général, sur lequel la théorie physique est batie, a encore aujourd'hui le même caractère fondamental qu'à l'époque de Newton. La structure d'équations, des grandeurs et des données expérimentales constitue encore aujourd'hui la base de toute théorie physique," Frank, P., *La Fin de la Physique Mécaniste*, Paris, 1936, p. 43.

[31] Whyte, L., *Critique of Physics*, New York, 1931, p. 123.

be applied and when and where. Physical-mathematical systems did not develop out of a vacuum. They are not applied to one.[32]

The precision of our models in their relation to the real world is another question. Einstein, who still believes in the eventual possibility of giving an exact model of reality with the further progress of physics, suggests that models be retained and modified according to the lacunae required by the Heisenberg principle.[33] If physics today is materially physical and formally mathematical, we must advert not only to the way we are studying the real world but also to the world we are studying. The neglect of physical can only result in a fiction-world leading to skepticism, bringing the death of science itself. Dantzig finds models in "tensors and matrices, manifolds and their curvature, differential forms and their invariants. The continual use of such terms and phrases has finished by converting them into so many new patterns and to the extent that they conjure up in the minds of the experts definite physical situations, these weird patterns fulfill their purpose as fully as did the classical mechanical models."[34]

Vaihinger, in his philosophy of *Als Ob*, suggests that models are pure fictions. The scientist proceeds *as if* they existed. He has no right to make them real. They are the subjective tools of the mind searching after truth. Sense perception alone is real.[35] Idealism has made a strong bid among the ranks of modern scientists who write either formal tracts or *obiter dicta* on the philosophical implications of their work. Impressed with the mathematical superstructure of their science and its apparent disagreement with common sense, they exaggerate the activity of man's mind, just as positivism exaggerates its passivity. They separate the familiar and scientific worlds.

Eddington and Jeans have carried the idealist position among physicists to an extreme form. For Eddington, the world can be built out of a "formless background" with "Hamiltonian differentiation of an invariant function of the 16 measures of struc-

[32] Benjamin, A. C., *The Logical Structure of Science*, p. 258.

[33] *On the Method of Theoretical Physics*, p. 19.

[34] *Op. cit.*, p. 231.

[35] *Die Philosophie des Als Ob*, Leipzig, 1920, p. 186.

ture."[36] The familiar table known by common sense is, it is said, in a different world from the scientific table composed of electrons scattered through relatively vast stretches of empty space. Reacting from the Hegelianism of his erstwhile colleague, MacTaggart, Eddington becomes so puzzled by the meaning of existence and of objectivity[37] that his philosophy is wholly colored with a skeptical idealism. Laws are imposed by the mind. "Our whole theory [relativity] has really been a discussion of the most general way in which permanent substance can be built up out of relations; and it is the mind which, by insisting on regarding only things that are permanent, has actually imposed these laws on an indifferent world."[38]

For Jeans, "the final truth about a phenomenon resides in the mathematical description of it."[39] Science does not describe the world. It treats of only man's sense perceptions.[40] The universe is a "mental concept."[41] It is pure thought of God, whom Jeans, echoing a Greek maxim, describes as a pure mathematician.[42] Mathematics is the only reality. "That is all you know and all you need to know."

Eddington and Jeans are extremists. They do not represent the views of sound-thinking scientists in their popular works. Much less do they represent genuine philosophy. Their treatment of ultimate realities may be boiled down to a universalizing of the scientific method.[43] Because their books are written in popular style, the authors have gained wide recognition.

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[36] *The Nature of the Physical World,* pp. 230-241.

[37] *New Pathways in Science,* New York, 1934, p. 291; *The Philosophy of Physical Science,* p. 69: "The purely objective world is the spiritual world; and the material world is subjective in the sense of selective subjectivism."

[38] *Space, Time, and Gravitation,* Cambridge, 1929, p. 197.

[39] *The Mysterious Universe,* p. 176.

[40] *The New Background of Science,* New York, 1933, p. 259.

[41] *The Mysterious Universe,* p. 167.

[42] *Ibid.,* p. 168, p. 165.

[43] Russell has pointed out the arbitrary character of the attempt by Eddington and Jeans to reconcile religion and science on the basis of the scientific method. "Eddington deduces religion from the fact that atoms do not obey the laws of mathematics. Jeans deduces it from the fact that they do," *The Scientific Outlook,* p. 108.

It is not the business of scientific method to pass upon the objectivity of the universe and its ultimate structure. Physics can only measure matter. It cannot subject it to the intellectual analysis and synthesis employed by philosophy. Both Eddington and Jeans believe that they have explained away substance. They conceive it to be the solid resistant stuff in the outer world known to the sense of touch. In reality they have misconceived the traditional doctrine of substance. Substance is not the stuff we feel and touch. It is a being able to exist in itself. It need not inhere in another reality. An intelligible principle, it can be studied only intellectually. It is inaccessible to the method of physics.

Eddington and Jeans, who leave no legitimate place for a philosophical approach to reality, are victims of their own failure to distinguish methods. The familiar table of Eddington is a real table. But scientific method can only deal with aspects of its reality. The physicist must accept the familiar table before he can apply the analytic technique of his science. Contrary to Eddington's belief,[44] the physicist must borrow his raw materials from the familiar world. He must likewise check data, eventually in terms of the familiar world.[45] Our concepts in science are all, in their ultimate origins, formed from every-day life.[46] As Planck has written,

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[44] *The Nature of the Physical World,* p. xiii.

[45] "For there is nothing peculiar about the physicist's manner of perception; the world which the ordinary man perceives is also the world which he perceives; the only difference is that he perceives it under carefully selected conditions, in order that he may examine it more closely. . . . They (objects perceived by the physicist) must, that is to say, in so far as they are directly apprehended in sensory experience, possess in common with the objects of the every-day world such qualities as shape, size, colour, and temperature. If they did not possess these qualities, it would not be possible for the physicist to have sensory experience of them," Joad, C. E. M., *Philosophical Aspects of Modern Science,* pp. 129-130.

[46] "I venture to suggest that it is as absurd to say that there is a scientific table as to say that there is a familiar electron or a familiar quantum or a familiar potential. Eddington insists upon the lack of familiar parallels in the latter cases; surely he is justified in doing so. What is puzzling in his view is that there are parallel tables. . . . But if the 'scientific table' is to be regarded as the produce of the 'raw material of the scientific world,' how can it be regarded as parallel to the familiar table?" Stebbing, L., *Philosophy and the Physicists,* London, 1937, p. 58.

the common sense world "is an indispensable aid to the groping imagination of the investigator, supplying him with ideas without which his work remains unfruitful. . . ."[47]

The capital distinction which Eddington fails to make is that between subject-matter, or material object, and the point of view which a given science takes, its formal object. "In other words," Joad remarks, "there must be something which is other than the description to correspond with the description which is given to it; and it is to this something that the description applies."[48] The same neglect of distinction can be noted in the philosophy of Jeans. His final doctrine is that mathematics is the ultimate structure of the real. This is a confusion of subject-matter and point of view. "To say that the external world obeys mathematical law and to say that it *is* mathematical law is to make two very different assertions."[49] One is reminded of the aphorism of Leibniz, "Toute philosophie est vraie en tant qu'elle affirme, et fausse en tant qu'elle nie." Mathematics is included in the formal object of physics. It does not follow from this that mathematics is the only kind of being nor that the empirical approach is the only method of knowledge. *Qui bene distinguit bene docet.*

To relate the world of science to the world of common sense, Whitehead has proposed a three-fold division of objects. Perceptual objects are the " 'things' which we see, touch, taste, and hear . . ." as tables, stones, chairs, and so on;[50] sense objects are secondary qualities like color and sound, the proper objects of the senses;[51] finally, scientific objects are those entities like atoms, electrons, and quanta which "are inferred by reason of their capacity to express these characters, namely they express how it is that events are conditioned. In other words, they express the causal characters of events."[52]

In his division, however, Whitehead does not make the distinction between "thing" and "object." Without this distinction, his

[47] *The Universe in the Light of Modern Physics,* pp. 10-11.
[48] *Op. cit.,* p. 77.
[49] *Ibid.,* p. 76.
[50] *Principles of Natural Knowledge,* p. 83.
[51] *Ibid.,* p. 83.
[52] *Ibid.,* p. 95.

views slope toward idealism, or at least agnosticism. For this reason too, the division does not explain how the scientific world can rejoin the world of common sense. A more orthodox philosophy sees the reason for this juncture in two principles: a) the "thing" is common to perception, to sense, and to science; and b) each one of these has a different "object" which is a real aspect of the "thing" proportioned to the knowing instrument, whether it be common perception, sense cognition, or systematized empirical science.

As in the case of Eddington's scientific table, it must be affirmed that scientific objects are derived ultimately from the conceptions of common sense. They bear the birthmarks of their origin. They must have physical properties, for they are still physical beings. An electron or a quantum is not merely a scientific *object.* It is a thing, the empirical aspects of which are objects of scientific analysis and the ultimate constituents of which are the interest of philosophy. A table or a stone is also a scientific object in this sense. It is a thing that has empirical aspects, just as an electron or a molecule. Scientific objects seek after the causal constituents of perceptual objects, as Whitehead indicates. In the process of study, the scientist merely refines the notions of common sense. His concepts and his symbols do not bear upon a different world. They merely represent empirically and in refined and corrected form the same world of common sense.

In summary, Whitehead writes: "The 'causal components' of a physical object are the scientific objects which occupy parts of the situation of the physical object, and whose total assemblage is what constitutes the qualities which are the apparent character which is the physical object apparent in the situation."[53] In this passage, Whitehead commits his usual failure to distinguish "thing" and "object." Hence, there can be no aspects to physical reality except that studied by science. Secondly, he fails to recognize that scientific entities also have apparent characters; otherwise, they could not be studied in physical experiment. Thirdly, this identity of "thing" and "object" and the dichotomy of real and "apparent" characters do not leave room for the extra-subjective thing where the ideas of the scientist and the *aspects* of *reality* that he studies

[53] *Ibid.,* p. 189.

may meet in the *tertium quid*, reality, which enables theory and the entities it describes to avoid a vicious circle and which makes knowledge objective. Hence, Whitehead's system of objects veers toward idealism.

The methodological agnosticism of Vaihinger is rejected by the success of physics in predicting phenomena through the analysis of its mechanical and mathematical constructs. The philosophies of Jeans and Eddington—and the spirit of idealism among physicists generally—results from a failure to distinguish the empirical method of physics and the abstractive, analytico-synthetic, intellectual method of philosophy and from their consequent failure to distinguish the various formal objects (or points of view) that may bear upon the same subject-matter. Whitehead's idealist tendency also results from this failure.

A realistic philosophy does not insist that every idea in the system of physics be a copy of an existing being. Maritain characterizes the domain of modern mathematical physics as a "pseudo-ontological world where being of reason abounds."[54] But the beings of reason here are not purely logical constructs. They are *entia rationis cum fundamento in re;* they are akin to Plato's myths, grounded in reality but metaphorical in their ultimate form.[55] Science thus becomes a type of speculative art.[56] Rousselot held that Aquinas would have so characterized modern physics.[57] Art in the strict sense is not a way of knowing. It is a way of making. But here there is no question of pure art. The system of physics is not designed, so say the forward-looking men in the field, to know the ontology of matter. It is only to predict the results of experiment. The mode of representing, as a result, may partake of the character of an artefact. But as far as it is representative, it is knowledge. Hence, Maritain speaks of a speculative art, an art for knowing.

[54] *Op. cit.*, p. 363.

[55] *Ibid.*, p. 310, pp. 318-319, pp. 273 ff. Naturally not every being in physics is of this type. Cf. also: Benjamin, A., "On the Formation of Constructs," *The Monist*, vol. 38, p. 40: "More precisely, a construct or fiction might be defined as any concept whose content is determined to a greater, rather than lesser, degree by the selective and creative activity of the mind, and whose value as an element of knowledge is to be measured not by the accuracy of its correspondence with reality, but in terms of its capacity to explain."

[56] Maritain, *op. cit.*, p. 319.

[57] Rousselot, P., *L'Intellectualisme de Saint Thomas*, Paris, 1924, p. 146.

Bergson claimed that the human mind distorted its object, that it did not attain the real.[58] He therefore seemed to make knowledge almost a complete artifact, virtually the work of the *homo faber*. Maritain's insistence on the real foundations of human knowledge in science as well as philosophy avoids the extreme view of Bergson and the idealists. It provides the foundation for a realistic appraisal of the noetic character of science.

Hoenen has proposed the view that physical theories, properly tested, express an analogical relation to reality and that if superfluous elements are eliminated by proper experiment and reasoning, the relation may become univocal.[59] It is difficult to see how this latter relation could be brought about, even on the condition imposed by Hoenen, since, in dealing with a *hypothetical* cause, we cannot determine whether we have eliminated superfluous elements.[60] Hoenen bases his arguments for at least an analogical relationship between theories and reality, on Cajetan's principle: *Quidquid assimilatur simili ut sic assimilatur etiam illi cui illud tale est simili.* Maritain has insisted that this view must be tempered by a proper definition of the type of analogy which obtains in scientific theories. It is not, Maritain holds, an analogical cognition in the strict metaphysical sense of analogy; it is a relationship of symbolism.[61] Though they may seem distant in their terminology, the difference between the two thinkers may be one of words and not of ideas. Theories are not mere fictions. They may not be in one-to-one correspondence with reality. But they have a physical counterpart in some form.

Cohen has summed up the case against those who regard scientific theory as a mere mental figment: "But this fails to explain

[58] *L'Evolution Créatrice*, p. 131.

[59] "De valore theoriarum physicarum," in *Acti Primi Congressus Thomistici Internationalis*, Rome, 1925, pp. 61-74; pp. 269-275; "Inquisitiones criticae in theoriam atomicam physico-chimicam ejusque valorem pro philosophia naturali," in *Gregorianum*, 1927, pp. 228-242 and pp. 417-442.

[60] Rousselot, *op. cit.*, p. 104, argues forcefully that all human knowledge is analogical, in the intellectual order.

[61] *Op. cit.*, pp. 85 ff.

why phenomena seem to occur as if the law of gravitation with its inverse squares were true, or why the properties of circular functions have proved most potent instruments for the discovery of important facts in almost all branches of physics. Doubtless equations are not vibrating strings; but is it not straining the dualistic dogma to assert that they have nothing to do with each other? Do not let us be misled by the term 'expedient' or 'invention.' A map or a chart is an expedient or invention. Yet if it fairly represents its objects, is it not because certain relations between its part are precisely those between corresponding parts of the objects represented?"[62]

Concepts of science actually work. Even technical symbols like a so-called psi function of wave mechanics or the gravitational components in the theory of general relativity have passed the test of experiment by which scientific theories must stand or fall. Though scientists may not be interested in the exact objective significance of their hypotheses, it is only by a mental blind-fold that we can completely sever the world of theory from the world of things.

Perhaps this whole problem could be avoided if it were asked in different terms. Our problem is not to demonstrate that scientific concepts bring the mind into conformity with the real world but to search out the noetic value of this scientific knowledge. Inductive judgments, as van Benthem states, are a fact.[63] Similar recognition must be accorded to the relation of theory and experiment. Given the space and time coordinates of a particle obedient to the law of falling bodies, we can predict its velocity at a given future moment. Wave-functions enable the physicist to predict with a high degree of probability phenomena which are verifiable in laboratory tests. Relativity predicted the deflection of light in a solar eclipse and accounted for the deviations in the perihelion of Mercury. We need not ask whether certain relations hold once they have been shown to exist by adequate experimental evidence. The problem of conformity is solved. The problem then becomes:

[62] *Op. cit.*, p. 227; cf. also by the same author, "The Logic of Fictions," *Journal of Philosophy*, 1923, p. 447.

[63] *Essai sur l'Induction, Son Domaine, Son Fondement*, Zwolle, Holland, 1923, pp. 2-4.

what degree of conformity does our mind have with the objective world? Even though the answer may be in certain cases that we have only reached a being of the reason, founded in reality, the conformity is still there. The work of the scientist is focussed on the correction and improvement of his theories to bring about their more thorough correspondence with reality.

No one has ever seen an electron, nor an atom either, for that matter. Yet we can arrive at a knowledge of correspondent realities, even though this knowledge may be moulded into the form of a mental construct. Though Whitehead's vivid language may overstate the thought, it is true that if "atoms are merely conceptual, yet they are an interesting and picturesque way of saying something else which is true of nature."[64] Imagination cannot picture the non-Euclidian spaces of the general theory of relativity. Yet it is possible to interpret these spaces by analogy to the so-called Euclidian space of sense intuition and thus to gain some knowledge of their nature. If physical concepts cannot claim at least an ultimate contact with the real world, then physics is not a science of the real. Theories successfully predict real phenomena. Only on the premise that they reach objective causes and reasons somewhere in nature can we find a sufficient reason for the successful prediction.

The coherence theory of truth, which has been suggested as a necessity of the method of hypothesis, as far as it hypothesis, does not rule out the conformity doctrine altogether. Scientific theories must adopt the coherence doctrine as a *formal* standard of truth. Pragmatism is a *sign* of truth. Yet in a *material* sense, there is a correspondence with the real world.[65] Theories cannot reach the world of existence through content. But they reach it in an indirect way through successful prediction in the existent world. By the very nature of hypotheses, we are forced to posit a cause which is consistent with the effects rather than one which is, and *is known to be*, their real ontological determinant. For even if it were the true cause and would never need subsequent correction, how could

[64] *Concept of Nature*, p. 45.

[65] How these statements can be reconciled will be discussed in the following chapter, dealing with scientific method from the point of view of strict logic.

we be certain of this relation? Hypotheses are not facts. If so, they are no longer hypotheses. They must be judged by different standards. But all theories, even as theories, when they are congruous with the effects as shown by proper experimental evidence must in some measure correspond to the real. The new theories must embody in their make-up the representational scheme which made the old theory, provided it had adequate empirical check, a successful instrument in accounting for facts. Otherwise, we should not be able to explain the success of the old theory, as Bohr has done with his correspondence principle and as Einstein has done in validating Newtonian mechanics for ordinary space and low velocities.

It was Francis Bacon who first spoke of crucial experiments to decide between two rival answers to a problem in nature.[66] Today, the *instantia crucis* is still regarded as being the reliable test between two competing theories. The prediction by a theory of facts which are not likely on any other assumption constitutes the surest guarantee of its validity. But in crucial experiments, how do we know that we have a real dilemma? How do we know that there are no other possible alternatives? "'Crucial experiments,' we must conclude," according to Cohen and Nagel, "are crucial against a hypothesis only if there is a relatively stable set of assumptions which we do not wish to abandon. But no guarantee can be given, for reasons we have stated, that some portion of such assumptions will never be surrendered."[67] Since we cannot be certain that we have ruled out all *real* alternatives in a crucial experiment, our experiment can reach no further conclusion than one "which shows that the effects deduced are congruous with an already posed principle." This is additional evidence that whatever the degree of *material* correspondence with the real world, theories in physics, from a *formal* point of view, must be judged in the light of the coherence theory of truth.[68]

[66] *Op. cit.*, vol. 4, pp. 180 ff.

[67] *Op. cit.*, p. 221.

[68] In experiments, especially in cases of the experimentum crucis, questions are posed in the light of the theories to be tested. In this sense, "Every measurement first acquires its meaning for physical science through the significance which a theory gives it," Planck, M., *Where Is Science Going?* p. 92. In this sense, "No universal judgment of science, then, expresses in and by itself a determinate meaning. For every such judgment is really the abbreviated expression of a meaning which would require a whole system of knowledge for its adequate expression. It is this larger meaning, which, so to say, animates the single judgments and gives them determinate significance," Joachim, H., *op. cit.*, p. 96.

In the foregoing discussion of scientific theory in its relation to truth, these three principles have been proposed: a) that theories are to be judged formally in the light of the coherence doctrine of truth; b) that the test of truth, which must by its very empirical character be a practical test, is pragmatic; c) that theories, because of their practical success, are in a material sense in correspondence with reality.

So long as the physicist employs the method of hypothesis—and employ it he must—he will not reach existent causes but only hypothetical ones. He will discover only "content." In his deductions, *existent* essence, the true middle term of demonstration will always be sought but will always prove elusive. According to the coherence doctrine of truth and according to physics, existence is sought through content. Traditional metaphysics covers both aspects when it refers to being as that which is. Here it is apparent why theories in physics are independent of the philosophy of nature; they cannot be subsumed under its ontological explanations of the real. Theories, as theories, in physics and a genuinely philosophical philosophy of nature can never meet. They do not contradict each other, complement each other, or coincide with each other. Theories emphasize content. Philosophy emphasizes being, the existent. So it is that the physicist is a perennial seeker. In Bradley's words, he takes the road of infinite regress, guaranteeing among other things the unlimited progress of his science. The bridge between content and existence just does not come within the purview of physics. So we have, in physics, that bridgeless gap between suppositions and true causes.[69] All the king's horses and all the king's men cannot span it.

[69] "Truth is the predication of such content as, when predicated, is harmonious, and removes inconsistency and with it unrest. And because the given reality is never consistent, thought is compelled to take the road of indefinite expansion," Bradley, F., *Appearance and Reality*, p. 165. Pragmatism, in its general sense, is equipped to serve the scientist in his search

It may now be asked whether theories are constructed to explain phenomena or laws, or if they merely describe the facts and generalizations of physics. The positivists tend to emphasize the descriptive character of science. For Comte, as it was already noted, "Every hypothesis, to be capable of being judged, ought to bear exclusively on the laws of phenomena and never on their mode of production."[70] This view in one form or another is a common doctrine of all the positivists. They rule out explanation from the domain of the sciences. They set up pure description as the end of knowledge. Description means, in the words of Bridgman, "to analyze nature into correlations, without, however, any assumptions whatever as to the character of these correlations."[71] Explanation on the other hand means interpretation in terms of causes.[72] A distinction is suggested between the two ideas on the basis that explanation seeks only after the *why* and description after the how.[73] But the questions are not fundamentally different. Description in its attempt at correlation must transcend the immediate data of sense knowledge as it becomes more and more complex. Eventually, it reaches causal determinants which are in

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for a self-consistent, all inclusive system. Thinking starts, according to Dewey, "from doubt or uncertainty. It marks an inquiring, hunting, searching attitude, instead of one of mastery and possession. Through its critical process, true knowledge is revived and extended, and our convictions as to the state of things reorganized," *Democracy and Education,* New York, 1923, p. 345.

That gap between content and existence is spanned by human intelligence and can never be traversed by discursive reason. It is what we shall later come to see as one of those immediacies which lie outside of physics and which is affirmed by man's mind, reflecting on experience in a judgment. Inseparable in reality but distinguished by man's mind, content and existence are reunited in judgment, reunited in the unity of being as seen by the reflective unity of man's spirit; it is this unity which renders both unnecessary and illogical the indefinite expansion required by scientific method (considered as a philosophy); by the coherence theory of truth; and by the pragmatism of James and of Dewey.

[70] *Op. cit.*, vol. 2, p. 318.

[71] *The Logic of Modern Physics,* p. 37.

[72] Meyerson, E., *op. cit.*, p. 65.

[73] Benjamin, A., *An Introduction to the Philosophy of Science,* p. 10.

the world of explanation.[74] Meyerson has effectively stated the case against positivism by showing that science is a study of the real and that it is explanatory by its nature as a science.[75] "Explanation," he writes, "consists in showing that given the ensemble of antecedents, that which follows can be inferred by deduction, being only the logical consequence."[76] This is precisely what the modern physicist attempts to do. If physics were purely inductive, positivism could argue more convincingly. But induction is only a state in scientific method as it is practiced. When deduction begins and one fact is shown to follow logically from another, we have projected, in at least a qualified sense, to explain consequents in terms of antecedents, not merely to describe the data.[77]

Theories tend to explain laws. In some way they tend to provide the causal background from which laws may be deduced.[78] The manner of explanation depends on the aspect of theory emphasized in the reasoning process. If it is a so-called mechanical theory, laws will be deduced by direct reference to the entities that form the causal determinants of the observed results. It is a well-known fact that Dalton's theory of the atomic constitution of matter was suggested by the laws of definite and multiple proportions. These laws can be deduced from the atomic theory.[79] On the other hand, the so-called mathematical theories, though they originate in physical pre-suppositions and refer to the physical realities of matter and energy which give meaning to their symbols, explain

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[74] *Ibid.*, p. 10, p. 197.

[75] *Op. cit.*, pp. 45-61.

[76] *Ibid.*, p. 67.

[77] "The mere sensory reception of any phenomenon does not constitute science; science is the causal arrangement of the phenomena, and the recognition is but the first step towards its achievement," Gotch, F., "On Some Aspects of Scientific Method," in *Lectures on the Method of Science,* p. 28.

[78] Campbell, N. R., *Physics: the Elements,* pp. 140-150.

[79] "Pourquoi le physicien, en parlant de la dilatation, etc., d'un barreau d'acier, ne peut-il le considérer simplement sous les espèces que lui fournit le sens commun? Evidemment parce que le phénomène de la dilatation serait alors inexplicable, alors qu'il semble s'expliquer si nous supposons le barreau composé de particules séparées par des intervalles, censés s'agrandir quand le barreau se dilate," Meyerson, *op. cit.*, p. 60. Meyerson adduces this example as evidence that science is explanatory.

laws by emphasizing their logical ancestry in theoretical mathematical formulae, derived from the physical presuppositions.[80]

A theory is not a mere collection of laws. It has an underlying unity which synthesizes the laws into an intelligible system and derives them as its consequences.[81] In this light, a theory may be said to explain laws and laws may be said to describe facts since the function of law is to generalize particular experimental results. This distinction is subject to restrictions. We think that we can explain phenomena by an appeal to laws, just as by an appeal to theory. In the case of theory, however, we have reached into a more ultimate domain. We reach what physics deems to be the logical and mathematical reasons for the laws themselves. In any case, physics is not purely descriptive. It is a science. As such, it seeks after causes, proximate causes by comparison with the ultimate principles studied by philosophy, but causes nevertheless. Confirmation of this point can be had by a perusal of the literature of modern physics and by noting the "because" clauses which are stated or implied in the systematic development of ideas. Moreover, the physicist does not merely describe what happens in a laboratory. He *expects* something very definite to happen on the basis of theoretical notions which he has ahead of time. *To expect* is close to the notion of *oughtness*, or binding force, necessary sequence (in the qualified sense of the word *necessary*). Why does the physicist expect this or that type of result? Because he thinks he knows the causal antecedents of these results, and such causes *ought* to have this or that effect.

But how may we qualify the notion of explanation in physics? Certainly, explanations by hypotheses are not absolute. There are two points of interest in treating this question: a) hypotheses are suppositions with which the effect is consistent; they need not formally be the true causes in themselves; even if they were, they could not, by their very hypothetical character, be known as such; and b) in a system that predicts the real, physics at least in a material sense has come to grips with reality. Taken in its complete form, we can judge theory to be at most consistent with the

[80] Campbell, N. R., *op. cit.*, p. 118.
[81] Bridgman, P. W., *op. cit.*, p. 42; Smart, H., *op. cit.*, p. 127.

effect. Perhaps another formal hypothesis could likewise "save the phenomena."

In discussing this subject, it may be pointed out also that theories tend to account for reality by mechanical entities that differ in degree, not in kind, from the observable data themselves and by mathematical computations that remain in the world of quantity. In explaining the determinants of experience, physics remains on the level of experience itself. The electron, proton, neutron, and other fundamental units into which the macroscopic world has been sundered by modern physics are all determinants of experience. They differ from the macroscopic world only in their size and in their physical properties. As Stebbing has said: "Science has its origin in an attempt to coordinate the facts of sensible experience, but in the discovery of the appropriate type of order, it passes to the consideration of a different order of *facts*."[82] But the proximate material and motor causes of matter are not sufficient to explain it in the precise sense. Matter, in its entitative character, is unintelligible without form. Efficiency demands final causality to make motion possible. In a genuine explanation, a hierarchy of causes must be recognized. A genuine, satisfying, realistic explanation, one that is in the order of the ultimates though not necessarily ultimate in that order, proceeds from the lower to higher, from the lesser to greater. Such an explanation transcends the world of phenomena. But it is found necessary by the fact that, on intellectual analysis, we find phenomena insufficient to explain themselves.

Similar reservations must be imposed upon the mathematical aspects of explanation in modern mathematical physics. In Meyerson's language, explanation is the process of reducing the multiple to identity. "In other words," he writes, there ought to be, if a phenomenon is to be explained, equality between cause and effect."[83] This identity takes the form of a mathematical equation. Aristotle wrote: "It is the business of the physicist to know the fact and of the mathematician to know the reasoned fact."[84] Mathe-

[82] *A Modern Introduction to Logic*, p. 230. (Italics mine.)
[83] *Op. cit.*, p. 156.
[84] *Post. Anal.* 79a, 1-5.

matics can explain facts when other facts are previously given, and the two sciences, the one, mathematics—a *scientia propter quid* —and the other, physics,—*a scientia quia*,—well go hand in hand as a means of explaining the real. Mathematics, the science of quantity and its relations, is well adapted to the physicist's need for logic and language since physics is concerned with the quantified, mensurable aspects of the universe.

But mathematical theory is a hypothetical explanation of the quantity and not of the ultimate ontological realities in matter.[85] Our mechanical and mathematical interpretations amount to explanations. But if the quantified aspects of matter do not constitute the only realities, neither do the corresponding explanations constitute the only knowledge.

Theories are limited in their truth-content by the fact that they do not reach real causes in the formal sense. The explanatory character of theory must be correspondingly limited. Models and constructs, it was seen, are necessary working principles which have a real foundation but are logically developed into their final form. They are necessary for the birth of mathematical theories, for their application to a physical situation. Both constructs and mathematical interpretations, however, can only render a cause which is consistent with the effects, as far as such antecedent reasons are hypothetical. This provisional character must likewise qualify our judgments on the way in which scientific theories explain. They are only provisional explanations, as was the Aristotelian theory of eccentrics and epicycles. The physicist of the future may find another way to "save the phenomena."

[85] Cf. This is the sense of Meyerson's verdict: "Le signe d'égalité signifie simplement que les choses sont égales par certains côtés ou le seront sous cértaines conventions," *op. cit.*, p. 139.

CHAPTER VII

Physics and the Problem of Proof

Great philosophy, like great literature, survives the age that produces it. Though it deals with the immediate problems of a span of history, it resolves them, in terms that transcend the incidentals of time and place, into the universal principles that man finds always and everywhere. Systems of thought which are bound up with the circumstances of an age perish with these circumstances. Great philosophy lives on.

Thomas Aquinas probed down to the universal truths which dissociate themselves from the incidental marks of his own age. They apply to all times and places. It is not to be a mere *laudator temporis acti* to develop and apply Thomistic principles to contemporary problems. They are not a mere museum of medieval thought. They are still valid today as the penetration into reality of that reason common to all men. But Aquinas did not say the last word for all times on truth and on reality. The principles which he propounded can be deepened, re-interpreted, and reapplied in the light of new facts and new speculations. Truth is one and simple. But this does not mean that it is humanly easy and that we envelop it once and for all in a philosophical classroom. For man, truth is not seen at a glance. It must be progressively deepened and widened in the span of time. Medieval thought assimilated and deepened the timeless principles discovered by the Greeks. Such principles are not ancient, medieval, or modern. They apply to all times. They are timeless. But each age is called to re-apply and re-explore their vast riches in the light of their organic, dynamic character. That is what is meant by *philosophia perennis*.

Philosophy is problem-solving. There must be problems before there are answers. Living at a time when empirical science had not yet acquired its autonomy—for specialization even in physics is always but a sequel to a general system—Aquinas found no need

to elaborate a formal logic of induction. The empirical sciences were treated in the philosophical synthesis. The logic of the two disciplines was not separated either. Inductive logic was not unknown either to Thomas or his contemporaries. His commentary on the *Posterior Analytics,* though principally concerned with the science of demonstration in the strict sense, is replete with direct answers to problems in logic that are sometimes thought to have arisen in the modern age. Finally, because they are timeless principles of all human thought, Thomistic principles enable us to erect a critique of the method of physics, just as the dateless cosmological principles of Aquinas enable us to assess philosophically the empirical discoveries about the material world.

The first problem, in appraising the method of physics, is to define the scope of the science. It has already been argued that modern physics is an intermediary science. It is formally mathematical because it is a science of measurement. It is materially physical because it is a physical subject-matter that is measured. Aquinas insists time and again on the correct notion of an intermediary science and on the observance of the limits which its formal object prescribes.

Pure mathematics considers its object as abstracted from matter. Such a science is pure geometry or pure arithmetic; one may also add pure mathematical analysis (the calculus). But knowledge can also be derived from the application of mathematics to material things. This is the case with astronomy or harmonics where experience or experiment supplies material for mathematical interpretation.[1] Another example of an intermediary science is the application of geometry to the science of perspective. Here we have mathematics applied to the study of physical lines.[2] The subordination of one science to another in this way corresponds to two questions that may be asked about an object: if it is (*quia*); and why it is (*propter quid*). The answer to the first question is provided by the lower of the two sciences which combine to form an intermediary science; the higher science is concerned with the second question.[3] Aquinas applies this viewpoint to a mathematical

[1] *In I Anal. Post.* 24.
[2] *In I Anal. Post.* 39.
[3] *In de Trin. Boeth.*, q. 5, a. 1, ad 5.

treatment of physical problems, as Aristotle had done before him.[4]

In such a concept of the hierarchy of the sciences, a discipline which provides the point of view for one science may in turn form the subject-matter for the science immediately above it. This is the case with perspective which is interpreted by geometry from one point of view and from another point of view interprets such phenomena as rainbows for the experimental physicist.[5] Aquinas is careful to point out that the subject-matter and the point of view assumed by the student are not in the same genus.[6] He insists that mathematics is the science of idealized quantity.[7] The world of real, quantified being on the other hand is the physical world. It may be studied in the light of so-called physical abstraction which prescinds only from the individuating characteristics of beings but not from the sensible material which they have in common. In an intermediary science which is mathematical in viewpoint on a subject-matter that is physical, the mathematical treatment is, as pure mathematics, on a different level from the subject matter.[8]

It follows immediately from the foregoing that mathematics does not exhaust the knowable universe of matter but remains extrinsic to its nature, as a *universe of matter.* If relativity theory and quantum mechanics are tending more and more to geometrize the world of mobile being, to reduce their accounts of the universe to the world-lines of the space-time continuum or to the position and velocity co-ordinates of wave-particles, the commentary of Aquinas on the *Posterior Analytics* provides a realistic basis for assessing the character of this new physics. It is unusual that Aquinas, in illustrating the *scientiae mediae,* should himself have so often used examples from geometry. These can be applied almost literatim to contemporary physics. "If indeed," Thomas writes, "things are the same by nature but are considered in the light of different principles, they pertain to different sciences. A mathematical body is not something separated from a physical

[4] *In Anal. Post.* 24.
[5] *In I Anal. Post.* 14.
[6] *Ibid.*
[7] *In de Trin. Boeth.*, q. 5, a. 3.
[8] *In I Anal. Post.* 14.

body. Still because a mathematical body is known through principles of quantity and a physical body through principles of motion, the science of geometry is not the same as physical science."[9] A science, Aquinas says, does not deal with any accidents whatsoever but only with those that come within the compass of its method. If geometry studies physical lines, it cannot pronounce on any of the principles associated with the lines in the physical world as physical. It applies to lines as lines.[10] Aquinas warns time after time against what Dr. John K. Ryan has called the fallacy of "alien method" whereby the method of one science is transferred to another science.[11] Every science has its proper questions, its proper answers, and its proper method.[12] No science may demonstrate conclusions in another.[13] In the case of sciences which are subordinated to each other, the formal object interprets the material object. Aquinas points out that, for example, arithmetic, a higher science, may deal with geometrical magnitudes, a lower science, from the arithmetical point of view.[14] But in this procedure, arithmetic remains arithmetic. It does not become geometry. It cannot prove geometrical principles. In the same way, mathematics applied to physics does not become physics. Geometry does not become an experimental science. *Diversorum enim diversa principia sunt.*[15]

In the opinion of Aquinas, the intermediary sciences are more mathematical than physical in their mode of explanation.[16] But they are physical in their foundations.[17] Applied to modern physics, this distinction means that mathematical physics is a science which relates the geometrical aspects of the phenomenal world. Its method is limited in point of view to the metrical. Though it is highly mathematical as a result, it still deals fundamentally or materially

[9] *In I Anal. Post.* 39.
[10] *In I Anal. Post.* 14.
[11] Cf. also Aquinas, *ibid.*
[12] *In I Anal. Post.* 20.
[13] *Ibid.*
[14] *Ibid.*
[15] *In I Anal. Post.* 41.
[16] *In de Trin. Boeth.*, q. 5, a. 3, ad 6.
[17] *Ibid.*

with the real world, not with the world of abstract mathematics. To apply this method to other fields of knowledge either by denying material foundations, in the manner of Eddington and Jeans, or by seeking in physics itself to interpret the internal constitution of the subject-matter, in the manner of philosophy, is to commit the error in the beginning of the knowledge process which can lead to grosser errors in the end.[18] There is a maxim in orthodox psychology: *psychologica psychologice traduntur.* Analogues of this may be applied to philosophy, physics, and mathematics.[19] Each should be treated in its own way.

Method, as the Greek parentage (μέτα ὁδός) of the English word suggests, is a way toward an end. The schoolmen, seeking the ontological truths behind the phenomena of sense, used a corresponding method. Induction was not unknown to them, even to Duns Scotus and Aquinas, the greatest of their metaphysicians. Though attaching various meanings to the word *inductio,* Scotus seems to have come to a genuine solution to the problem of induction. He pointed out that we can generalize from the repeated occurrence of phenomena to a universal principle. The regularity in the effects of necessary causes (which operate in nature) indicates that the effects are the natural results of such causes. They will therefore follow always and in all cases from such causes.[20] Aquinas, though not so striking in his vocabulary, laid down clear principles that might be used to interpret induction as applied in contemporary physics. His system—an organic thing which can ingest the truth wherever it is and assimilate it[21]— clearly leaves room for modern scientific induction while prescribing rules to avoid its errors.

Aquinas uses the word *inductio* to describe the abstractive operation of the intellect in reaching the universal from a sensible cognition of singular things.[22] He draws a contrast between induction and demonstration and points out that the universals reached through the former process furnish the premises of the latter.

[18] *De Ente et Essentia,* c. 1.
[19] *In I Anal. Post.* 20.
[20] *In I Sent.*, d. 3, p. 4, a. 2.
[21] Maritain, J., *Sept Leçons sur l'Etre,* pp. 17 ff.
[22] *In Anal. Post.* 29.

Traditional philosophy is not a completely deductive system. It begins in sense experience, Aquinas avers, otherwise it would not be scientific. Though universals are above space and time and in themselves are purely intelligible, they are known through induction.[23] Aquinas held firm to his reasoned realism on this point against the Platonism of his time which, by its essentialist metaphysic and its a priori, systematic character, suggests modern physical theory in more than a passing way. Genuine philosophy provides the only genuine, self-sufficient induction. Proceeding either directly through abstraction or through the equivalent of this direct abstraction (viz., reaching general principles through a reflection on nature's order) philosophy and not physics can keep induction on solid ground and give the necessary support to the conclusions of physics. Abstraction is not dreaming; it does not falsify or negate. Abstraction, the passing from singular to general, proceeds *per viam inductionis,* by induction from sense data.[24] Physicists are often unaware that whenever they think, as men, they are using this very abstractive power which Aquinas describes; they are unaware that knowledge is not empirically given as though pre-formed but must be wrested from nature by the application of thought to the data which are given. The whole of reality is not actually given. If it is, we might as well close our laboratories and destroy our literature. We are scientists, or rather would be, by simply opening our eyes if everything is given.

Thomas developed his doctrine of abstraction from the texts of Aristotle who wrote that it is "impossible to come to grasp universals except through induction. But induction is impossible for those who do not have sense perception."[25] Aristotle in turn acknowledges that induction goes back to Socrates.[26] In Plato, there are numerous examples of the Socratic method of definition.

[23] *Ibid.*

[24] *In II Anal. Post.* 20.

[25] *In I Anal. Post.* 81 b 5; cf. also *Top.,* A, 12, 105 a 13; *Eth. Nic. Z,* 3, 1139 b 28; A, 7, 1098 b 3; *Anal. Pr.* B, 21, 67 a 23. "Partir de l'expérience pour aboutir au concept, sélon Aristote est induire," de Corte, M., *La Doctrine de l'Intelligence chez Aristote,* Paris, 1934, p. 138.

[26] *Met.* XIII, 4, 1078 b.

It is a method of considering examples with a view to arriving at a definition.[27]

In the *Meno,* Socrates attempts to define virtue by his inductive method, eliminating all other attributes of virtuous persons until the common notion of virtue remained.[28] Plato elaborated on this method even further. He introduced the conceptual development of ideas. He proposed considering also "not only the consequences which flow from a given hypothesis, but also the consequences which flow from denying the hypothesis."[29] By a process of eliminating the false and the accidental, as in the case of defining virtue, a knowledge of essence can be reached.

Francis Bacon, it was already noted,[30] compares his method of induction, by exclusion, to the Socratic method of definition. As it was also noted, however, the Socratic method is based upon an intellectual analysis of being and not merely upon a merely mechanical juxtaposition of sense data. Plato's logic also prescribes a classification or division (διαίρεσις) of concepts by a method of dichotomy.[31] This suggests Bacon's catalogues of instances. But Plato points out that definition precedes division, because "the right way is, if a man has first seen the unity of things, to go on with the inquiry and not desist until he has found all the differences contained in it which form distinct classes."[32] This is the converse of the Baconian method which, having ruled out intellectual analysis, must make division the first step and definition only the second.

Thomas points out the short-comings of mere exclusion and mere division—things that Bacon later naively accepted. Following Aristotle, he recommends the Platonic method of definition. If we want to prove, he writes, that a wall does not breathe simply be-

[27] "The higher ideas, my dear friend, can hardly be set forth except through the medium of examples . . . ," *The Statesman,* in *The Dialogues of Plato,* trans. B. Jowett, New York, 1937, vol. 2, p. 304.

[28] *Meno,* in *op. cit.,* vol. 1, pp. 350 ff.

[29] *Parmenides,* in *op. cit.,* vol. 2, p. 97.

[30] Cf. *supra,* p. 2.

[31] *Phaedrus,* in *op. cit.,* vol. 1, p. 267; *The Statesman,* in *op. cit.,* vol. 2, p. 312.

[32] *The Statesman,* in *op. cit.,* vol. 2, p. 313.

cause it is not an animal, we do not attain to true causes and reasons.[33] We must know beforehand something of the essence of the phenomena in question if we apprehend the *why's* as necessities of being.[34] Perhaps, Aquinas adds, there may be animals that do not respire. In the method of division, Thomas followed Aristotle who, in turn, insisted with Plato on the deductive character of the process. In this principle, one finds ample argument against the pure induction of Francis Bacon in his catalogue of the Natural and Experimental History of Phenomena, the beginning of classification, and in his Tables, the end of the same operation. Through division alone, Aquinas notes, we cannot reach essences.[35] If it is said that man is either pedestrian or aquatic, it does not follow that since he is not aquatic he represents all that we mean when we say *pedestrian animal.*[36] We must know that *animal* is sufficiently divided as either pedestrian or aquatic. We must therefore know something of the nature of animal. We must know this so that it does not matter "whether the same method is used in many or few cases. The essence is the same in all."[37] Merely to note that man is pedestrian does not justify the view that his nature is such.[38] Necessary division is deductive and intellectual. These two properties insure that a correct order can be observed in the division and that only essential principles of division will be considered, not the accidental differences which may or may not be present.[39]

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[33] *In I Anal. Post.* 23.

[34] In this argument, Aquinas was relaying on the biological theories prevalent in his day. He states that the conclusion of the argument does not follow, since there are animals like fish which do not breathe. In the concept of animal, then the idea of respiration is not necessarily included.

Obviously, experimental facts have since contradicted the facts known to Aquinas himself as to the nature of fishes. But such new discoveries have not contravened the logic which insists on the intellectual analysis of quiddities in division and proof and which can be so tellingly applied to modern physics.

[35] *In II Anal. Post.* 4.

[36] *Ibid.*

[37] *Ibid.*

[38] *Ibid.*

[39] *In II Anal. Post.* 15.

This logic of division is not without direct bearing on the problems of modern science. In the classical system, matter and radiation were by and large fenced off into two inseparable domains. Quantum physics has brought them together. Yet, because in physics we do not know essences, is it not possible that our present classification of mechanical and optical phenomena may again be revised? The theory of relativity may make it possible to combine gravitation, electricity, and electromagnetism into a single mathematical treatment. But this does not mean that the phenomena are the same in their ontological status, apart from their mensurable aspects. Do the facts of symmetry and anti-symmetry in the treatment of quantum mechanical problems of wave-particles express deep, essential differences between the phenomena in question? Or can we say that one element in the periodic table differs from another simply by the addition of electrons in the orbits, i.e., of protons in the nucleus? Scientific method in itself does not reach essences and therefore cannot make essential definitions and divisions. It can only define and divide according to mensurable properties of the corporeal world which in themselves cannot be accepted as the signs of deeper, essential, really and truly ontological differences between things. Since scientific technique does not pierce down to the essences of things, which are intelligibly and not empirically attainable, its division and classification must suffer correspondingly. Division of itself does not constitute syllogistic necessity, Aquinas argues, because it leaves unanswered the question of *why* the conclusions are necessary.[40]

On the other hand, deductive division from previously abstracted notions is a way of arriving at true definition.[41] The reason is, as Aquinas indicates, that such a division is based upon common notions (essences) in which the subgroups are perceived in their relation to the whole class. The human spirit passes from the common to the special and not, after the manner of English empiricism, along the opposite path.[42] We cannot make an essential division in proceeding from the special to the common. But having attained the common, universal, and essential, we can see its rela-

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[40] *Ibid.*

[41] *In II Anal. Post.* 15.

[42] *Ibid.*

tion to the members. Only so far as we do this can we make essential divisions and classifications.

Aquinas approaches from another viewpoint the problem of division and definition by showing their inductive origins. In the process of *inducing* the definition of things, as he puts it, essential differences must be taken into account in dividing one thing from another. Thomas adds that this movement is from the less common to the more common.[43] It is an aid to teaching which should begin with familiar instances. It is also a noetic necessity. The mind can advance in true knowledge only from the known to the unknown. But this is, from a logical viewpoint, induction in the sense of abstraction. The mind grasps the essences of things, then compares and relates the genera and species.

As a case in point, Aquinas borrows an example from Aristotle. Suppose that we are searching for a definition of heroism. We will examine individuals who are heroic and attempt to discover their common characteristics. We examine Hercules, Ajax, and Achilles. We find that they would not tolerate wrongs. We examine Lysander and Socrates and find that they were unaffected by hardships. They bore them as they would good fortune. We conclude then that heroism consists in an indifference to good or bad fortune and an intolerence of wrongs.[44]

This process is the Aristotelian ἐπαγωγή. Aristotle, it is true, did not employ the word in this passage. Neither did Aquinas use the word *inductio* in his commentary. But ἐπαγωγή in Joseph's words "has come traditionally to be called the method of obtaining definitions by induction."[45] From the use of the term *inductio* elsewhere in Aquinas, it is clear that the Socratic method of definition was one of the senses he gave the word. Such a process begins in sense. It examines individuals. But it is intellectual and abstractive.[46] Any other method of division, any other method of

[43] *In II Anal. Post.* 16.

[44] *Ibid.*

[45] Joseph, H., *op. cit.*, p. 379.

[46] For Aristotle's notion of induction as abstraction, cf. de Corte, M., *op. cit.*, pp. 179 ff. "Elle ne peut donc être qu'une saisie immèdiate de l'universel dans le particulier," p. 180.

In commenting on this ἐπαγωγή, as Aristotle conceived it, Joseph says that it leads to an "inductively obtained *conclusion*" and adds that "the *conclusion* is certainly "syllogized," so that the *conclusion* may be what is "induced." It has, however, also been thought that the process of bringing up or citing instances, by means of which the conclusion, is to be established, is what the word was primarily intended to signify. (Bonitz, *Index. Aristotel.*, s.v. ἐπαγωγή, seems to take this view); and anyway the process described is one in which a general *conclusion* is established by citing the instances of its truth," *op. cit.*, p. 378, note. The word *conclusion* raises the problem of whether the ἐπαγωγή, developed from the Socratic method, is a process of abstraction or the result of a so-called inductive syllogism. Yet so long as we have only individual instances, we cannot infer a universal conclusion according to the laws of logic. *Aut semel aut iterum medius generaliter esto.* We can only arrive at a necessary medium through the process of universalization which is abstraction. Here we are face to face with the central problem of induction. The gap between the singular and the universal can only be bridged over by abstraction, not by enumerating singulars as though they could eventually form an adequate medium or middle term. Hence, Aristotle remarked that the process of induction does not have a middle term, and Aquinas noted that there was no medium between the individual and the species. Thomas' example then, like Aristotle's—since an adequate middle was lacking—does not seem to be a reasoning process but only a more elaborate form of abstraction. To say, as does Joseph, that the "conclusion is certainly 'syllogized'" is misleading.

[47] *In II Anal. Post.* 20.

classification, does not attain to essences, does not attain to necessity. Modern physics certainly does not meet these requirements. It divides, it defines, only as it measures, and measurement, a strictly empirical operation, stays strictly on the empirical level. It does not encompass essences. It does not reach the unchanging and the necessary.

The attitude of Aquinas toward experiment showed that he viewed induction as an abstractive operation. After an herb, for example, has been found by test, he declares, to have cured many men of fever, it can be accepted as a principle of art and science that the herb actually cures of fever.[47] Aquinas has merely applied here what Bacon later called the Table of Presences and what Mill formulated as the Method of Agreement. Yet our modern use of the term *induction* may befog the real meaning of this passage in the mind of Aquinas. Here too, he does not use the word *inductio;* but it is clear from his discussion of experiment that his method bears a striking resemblance to modern scientific technique. What is noteworthy, however, is that he does not believe

he is using an inductive "argument." He refers to the process as though it were an elaborated abstraction. The procedure, he remarks, "occurs through the possible intellect which, in turn, works by means of the active intellect which renders things actually intelligible by the abstraction of universals from singular cases."[48]

This process of abstraction liberates essences (known either in themselves or else, as in Thomas' present example, through effects) from their material surroundings and enables us to generalize our conclusions. The operation of abstraction depends on insight, not on formal reasoning, though afterwards we may revert to logic to justify the conclusion we have reached. Such a logic in fact was treated at length by Aristotle in his *Topics,* which deals with dialectic in the Greek sense and which prescribes, in the course of discussing disputation, ways of justifying principles arising through abstraction, hence not formally demonstrable. Dialectic in this sense is not formal logic. In the case of Aquinas' example, we should have to appeal to the regularity of the event and the regularity of nature to justify, against attack, that it is in the nature of this particular herb to cure of fever. In this respect, Thomas' example pertains to reasoning. He himself does not mention this fact. On the contrary, he states that the "conclusion" is a principle known by intellection and not through the termination of a process of discursive reasoning. The process seems directly to involve only apprehension, without recourse to argument in the syllogistic sense.

It is characteristic of the firm realism of Thomistic philosophy that the commentary on the *Metaphysics* of Aristotle should open with the discussion of the importance of experience as the beginning of knowledge. Experimental conclusions, declares Aquinas, arise from the memory of singular events which are collected and perceived as true by the cogitative interior sense in man, subordinated as it is, to the intellect's power for grasping intelligible and universal essences.[49] In addition to mere sense experience, Thomas says, man has universalizing reason by which he perceives the

[48] *Ibid.*

[49] What Aquinas, following Aristotle, says here pertains more to the psychology of discovery than to the logic of proof.

essences of things.[50] It is clear that knowledge begins in experience. But it is also clear that even experimental conclusions involve abstraction. It is ultimately through insight that the discrete data can be unified into a universal conclusion.

The role of abstraction in the life of reason, whether it be on the scientific plane or in the syllogistic arguments of philosophy, cannot be overestimated. Necessity is not found in mere regularity of sequence. Aquinas pointed this out long ago when he wrote: "Discovery is not always associated with certitude." Necessity does not rest on mere *is-ness* of relationships. It is rooted in their *must-ness.* A conclusion is said to be necessary when it cannot possibly be otherwise.[51]

Since the conclusion of an argument cannot be otherwise than it is, every valid argument must be reducible to first principles. The principles of identity, of non-contradiction, and of excluded middle are immediately evident from the notion of being. They constitute our first judgments about being. They flow from the notion of being without the mediation of the middle term of demonstration. Aristotle and Aquinas refer to them as the first, the true, and immediate principles which are self-evident.[52] They are seen in the very idea of being itself which is abstracted as the initial idea of the intellect.

But abstraction, as related to proof, does not stop here. The material as well as the principles are grasped by abstractive, intellectual insight into reality.[53] By apprehension, the intellect pierces to essences, whether known perfectly or through effects, of the things whose accidents are presented to the senses. It is this knowledge of essences which warrants the judgment that a thing cannot be otherwise than it is. The contingent, spatio-temporal, existential determinations of the material world make this type of certitude impossible on the level of phenomena as such.[54] Hence, demonstration is not attained by an enumeration of individual instances (the *inventio* referred to above). It is only possible by ascending

[50] *In I Met.* 15.
[51] *In I Anal. Post.* 1.
[52] *In I Anal. Post.* 3.
[53] *In II Anal. Post.* 1.
[54] *In I Anal. Post.* 14; I, 86, 4; *In de Trin. Boeth.*, q. 6, a. 1.

beyond the changing matter of time and space to the realm of unchanging universals. "Things are contingent," says Aquinas, "because of their material components; because contingent things can be or not be. Potentiality pertains to matter; necessity springs from form; because those things which spring from form are necessarily present."[55] Form and quiddity (essence) are bracketed together by Thomas.[56] Both are used to signify that which makes a thing what it is. Definition indicates form or essence.[57] If therefore we seek the roots of absolute necessity in nature, it is to the form or essence that we must penetrate. It is form or essence which makes a thing so that it cannot be otherwise. If it were otherwise, it would no longer be the same thing. Man could never be irrational and could never be a non-animal. He could not then be a man. An irrational man is a contradiction. Man cannot be a man and be other than he is. Through knowledge of essences,[58] we can see the connection between the subject and attribute in the premises. We see it as necessary and universal. The necessary conclusion follows from such premises as a necessary effect. The attributes, predicated of the subjects in the premises, are seen to be contained within the very definition of the subject. This intellectual insight is the ultimate work of abstraction, apprehending the quiddities of things.[59]

In view of the importance of abstraction, Aristotle, and also Aquinas in his commentary, commences the *Posterior Analytics* with a discussion of the foreknowledge required in demonstration.

[55] I, 86, 3.
[56] *De Ente et Essentia*, C. 1, Lect. 2.
[57] *In I Anal. Post.* 9.
[58] It is not necessary here to enter into a digression on the type of knowledge which we have of specific essences. This has been treated by Adler. M., *The Problem of Species*, New York, Sheed and Ward, 1940 (*passim*); and by Maritain, *op. cit.*, pp. 411 ff. Essential connections, as far as they are necessary, involve the problem of species in the material order in oblique fashion; essential, necessary, universal connections are rooted in being which is neither a genus nor species but is transcendental. Necessary judgments about material realities can be made once we attain to being, and we do that in the first intellectual experience we ever have. Only in so far as we reduce our knowledge of material realities to necessities of being is this knowledge necessary in character.
[59] *In I Anal. Post.* 1.

We cannot demonstrate everything. That would constitute a regression into infinity. We must commence with the self-evident, known through abstraction and seen to be necessary by its very definition.[60] Both Aristotle and Aquinas insist on definition as a preamble to demonstration.[61] Both distinguish two fundamental types of demonstration: a) causal demonstration (*demonstratio proper quid*, ὸιοτὶ ἐστίν) which demonstrates effect from cause and gives the reason why the attribute is necessarily predicated of the subject; and b) factual demonstration (*demonstratio quia*, ὸτὶ ἐστίν) which demonstrates cause from effect and merely affirms the necessary inherence of the predicate in the subject without being able to give a sufficient reason as seen in the subject itself.[62] In both types of demonstration, definitions are required. In causal proof, we must know what the subject is and whether it exists; we must also know what the accident is, though not whether it is, since this is to be established.[63] In the case of factual proof, since the existence of the subject must be proved, the question of what it is is preceded by the question, whether it is. The existence is proved from accidents. Here, however, we know of the subject what its name stands for.[64] In the factual demonstration, we must again know of the predicate what it is but not whether it is, exactly as in causal proof. Since, however, as Aquinas says, all demonstration begins with abstractions from the existential world of sense, the existence of the predicate is known at least in parts from some other subject. We cannot know essences unless we have first apprehended as well the existence of some subject.[65]

Aristotle and Aquinas point out that science is the search after a middle term.[66] This is known from the definition of the subject and the definition of the predicate. Because they consort

[60] *In Anal. Post.* 9.
[61] *In I Anal. Post.* 4.
[62] This does not mean that there is no sufficient reason in the subject but only that the sufficient reason, not being seen from the subject out, must be known from the effect rather than the cause.
[63] *Ibid.*, cf. Bennett, O., "St. Thomas' Theory of Demonstrative Proof," in *Proc. Amer. Cath. Phil. Assoc.*, 1941, pp. 76-88; *In I Anal. Post.* 1.
[64] I, 2, 2 ad 2.
[65] *In I Anal. Post.* 30.
[66] *In II Anal. Post.* 1.

in the middle term, they are united in the conclusion of the demonstration.[67]

It is rightly then that Aquinas refers to definition as the medium of demonstration.[68] If science is the knowledge of causes, the middle term is the cause which makes science possible.[69] It is thanks to definition that Aquinas can say that before the conclusion is actually drawn, it is known in some way since it is contained causally or potentially within the singular cases from which it is drawn.[70] Abstraction then, by which the mind grasps first principles and lays hold of the subject, predicate, and medium of demonstration, is an indispensable tool of the reasoning process. Without it, science would be impossible. For it could not compare and correlate the individuals of the sense world as individuals since every individual as such is unique and incomparable. It is small wonder then that we look in vain for a pure system of positivism.

The traditional concept of insight by abstraction has been lost by those modern thinkers who attempt to reason from mere collections of data and who base their conclusions on the enumeration of instances. For Aquinas, intellectual insight is a way to the nature of things which, under penalty of contradiction, cannot vary while remaining the same nature. Once the nature of a thing is gripped by man's intellect, he can then demonstrate its essential or proper interrelationships in a way that "nothing can be more certain than that the opposite is false."[71] There is no science of the purely incidental. Without corrupting the subject, incidental things can be or not be present.[72] Through abstraction, insight into form or essence, we discern whether a predicate is a separable accident or a proper one, which, while not being part of the essence of a thing, flows necessarily from the essence. If we were ignorant of the essences of things, we could not judge whether the predicate, as a qualification of the subject, was separable or not.[73] No attribute

[67] *In Anal. Post.* 4.
[68] *In I Anal. Post.* 26, 30; *In II Anal. Post.* 9.
[69] In *II Anal. Post.* 9.
[70] *In I Anal. Post.* 2.
[71] *In I Anal. Post.* 5.
[72] *In I Anal. Post.* 31.
[73] *In I Anal. Post.* 36.

can be defined without the definition of the subject from which it flows and of the relations, proper or incidental, which it bears to the subject.[74] Just as the premises of demonstrative proof employ necessary interconnections among the subject, the middle term, and the predicate, so in the conclusion the dependence of the predicate on the subject is not incidental but proper, i.e., necessary.[75] *Demonstratio est ex necessariis et de necessariis.*[76] Aquinas sums up his doctrine on the nature of scientific proof by affirming, with Aristotle, its universal and necessary character: "For science does not treat of the singular cases which fall under the senses. . . . And another character is that science deals with the necessary, that is, with what cannot be otherwise."[77]

In this chapter, it was seen that contemporary physics is an intermediary science that is physical in its subject-matter and mathematical in its viewpoint. Induction as an abstractive process was examined and related to the problem of definition and division. It was seen that physico-mathematical science, since it does not employ abstraction as a formal principle of method, does not attain essences, whereas philosophical induction does. It follows that since abstraction is necessary for strict proof, physics does not reach the premises necessary for genuine demonstration. Such an office belongs to philosophy, which employs intellectual analysis on the same subject-matter that physics measures and correlates.

[74] *In I Anal. Post.* 1.
[75] *In I Anal. Post.* 9, 30.
[76] *In I Anal. Post.* 13.
[77] *In I Anal. Post.* 42.

CHAPTER VIII

Law, Theory, and Logic

Induction in the philosophical sense is abstraction. When Aquinas drew his frequent contrast between induction and the syllogism, he meant induction in this sense.[1] In the same trend of thought, demonstration is contrasted with induction.[2]

Aristotle employed the word induction (ἐπαγωγή)to characterize the process of establishing a general proposition by affirming its truth in each particular case. To take Aristotle's example: Man, the horse, the mule are long-lived. Man, the horse, the mule are bileless. Therefore, all bile-less animals are long-lived.[3] In this argument it is at once apparent that the middle term is not distributed. But Aristotle himself was aware of this. He takes it into account by insisting that the enumeration must be complete, must embrace all bile-less animals, if the argument is to be formally valid. In such an event the minor can be converted into the proposition, all bile-less animals are the man, the horse, the mule. Hence, the argument becomes formally correct. Aristotle thus conceived of the inductive syllogism, as it is called, as induction by complete enumeration, a fact that drew sharp criticism from Francis Bacon.

From criticism on this point, Aristotle cannot wholly be exonerated. If we grant that by complete enumeration, the minor premise can be converted and the argument can become *formally* valid, still from the point of view of material logic, there are three objections to the process: a) how can we overcome the tremendous practical difficulty of counting all the instances of a middle term; b) how can we be sure that our enumeration is complete even spatially, let alone temporally and with regard to future samples; c) finally, the conclusion in an individual case must be affirmed experien-

[1] *In I Anal. Post.* 1, 21.
[2] *In I Anal. Post.* 7.
[3] Ana. Prior III, 68 b 15 ff.

tially before it can be drawn from the inductive process. The whole argument therefore is sterile. It cannot give rise to new knowledge because the conclusion of the individual cases is already foreknown. Mill's attack on the syllogism is based on a misconception of what Aristotle and Aristotelians hold. But applied to the enumerative induction of Aristotle, the arguments carry weight.[4]

Aquinas noted the weakness of enumerative induction. He points out the necessity of subsuming every single instance under a purely enumerative generalization. *Oportet supponere quod accepta sint omnia quae continentur sub aliquo communi. . . .*"[5] If we argue, for example, that Plato, Socrates, and Cicero are running, we cannot generalize this fact to include all men.[6] Running is an incidental thing. The mere enumeration of instances (*via inventionis*) does not disclose the nature of the being in question. So long as we are ignorant of the type of connection between subject and attribute, we must allow for the possibility that the next instance we examine will be at variance with the foregoing.[7] Not every predicate indicates the essence of the subject, Aquinas declares, nor does it reveal how the attribute is ordered to the subject.[8] It was Aquinas, long before Bacon and Mill who said against purely enumerative induction: "He who passes by induction from singulars to universals neither demonstrates nor syllogizes in a necessary way."[9] Thomas laid down two characteristics of a universal: the attribute must be contained within the subject, no matter how the subject may be qualified in other re-

[4] In addition to enumerative induction which terminates in a *collection* of individuals, Aristotle recognized another way to general principles. It is the method of induction, considered as abstraction; for "there is an originative source," he writes, "which enables us to recognize the definitions," *in I Anal. Post.* 72 b 20. Whatever may be said about enumerative induction does not pre-judge the syllogism; Aristotle conceived man as endowed with the intellectual power to see in one lone example of being truths that apply to all being.
[5] *In II Anal. Post.* 4.
[6] *Ibid.*
[7] *Ibid.*
[8] *In I Anal. Post.* 10.
[9] *In II Anal. Post.* 4.

spects;[10] it must be contained in the subject independently of time.[11]

The principles which Aquinas found in being and in our ways of knowing it can be aptly applied to the method of physics. Physics is governed by these principles as much as philosophy. They govern the correctness of thought and the firmness of certitude. Such laws were not fabricated by Aquinas nor by Aristotle nor by the tradition which both represent. They are dictated by the nature of being and by the nature of human knowledge. Philosophy does not accept the argument from authority. Its sole guide is reason. Scientific method must be submitted to examination by philosophy, not because it is Thomistic or Aristotelian philosophy, or Kantian or Cartesian. Reason itself imposes standards by which the method must be judged.[12] There are two paramount questions involved in the critique of method in physics: the question of law and the question of theory.

A law, as it was already observed, is a generalization of empirical fact in physics. In view of the short-comings of purely enumerative induction, a crucial problem, in Campbell's words, "arises from the necessity that the relation established by a law shall be valid, not only for that portion of experience on which the evidence for the law is based, but also for experience received subsequently and known at the time of establishment."[13] So long as our knowledge of the past rests upon a mere regularity of occurrence, we cannot, on the level of empirical science, conclude to a similar regularity in the future. If the middle term is a particular or a mere collection of particulars, we cannot draw a universal conclusion.[14] Even if we did, it could contain nothing new. Though necessary truths can be drawn *from* contingent things by abstraction, necessary conclusions cannot be the result of contingent media as far as they are contingent.[15] Built on a middle term abstracted by the intellect, demonstration is not made more certain by merely multiplying the number of contingent media.[16] For the universal itself is not a mere summation of instances.[17]

These principles have a direct bearing on modern physics. Law is empirical in physics. Physics deals with the world of sense, where a knowledge of intelligible essence is precluded by the scientific method itself. Necessary truth, it has been noted, demands the ascent of the mind to essences abstracted from their immersion in matter. By a simple enumeration of the singular cases of the sense world, how can we know, Aquinas asks, that an attribute can be predicated in all possible cases and that no contrary instance is possible?[18] If induction of law in physics depends on mere enumeration, a mere solitary contrary instance can disprove it.[19] On the contrary, a knowledge of universal truth rests not on sense but on intellectual insight.[20] It is always and everywhere present in a thing as a result of the thing's nature.[21] Everywhere and always man is a rational animal; motion demands a mover; being demands order. Otherwise man would no longer be man, nor motion motion, and so on. The nature is seen by insight, not by counting. Here it differs from a mere collection. It is only in modern times that the emphasis has been placed not upon nature but upon number. D'Abro, for example writes: "In short, it is in the accuracy with which the facts are studied and co-ordinated, and it is in the number of facts considered, that the scientific method differs from all other methods. Therein rests its superiority."[22] But no matter how accurately a ratio expressed by law may be measured or how numerous the ratios may be, reason does not leave room for an immediate, empirical conclusion to the necessity and universality which are the characters of science.

[10] This principle suggests Newton's third rule of the Rules for Philosophizing, cf. *supra*, p. 74. However, Aquinas was speaking of genuine universalization through an abstracted knowledge of essences. Newton was speaking of generalization through enumeration.
[11] *In I Anal. Post.* 8.
[12] Cohen and Nagel, *op. cit.*, p. 278.
[13] Campbell, N. R., *op. cit.*, p. 89.
[14] *In I Anal. Post.* 7.
[15] *In I Anal. Post.* 8.
[16] *In I Anal. Post.* 21.
[17] *In I Anal. Post.* 10.
[18] *In II Anal. Post.* 5.
[19] *In I Anal. Post.* 12.
[20] *In I Anal. Post.* 40.
[21] *Ibid.*
[22] *Evolution of Scientific Thought from Newton to Einstein*, p. 384.

The mere multiplication of instances, no matter how conditions may be varied in accordance with such requirements as the five canons or Newton's third rule, does not constitute an adequate medium for demonstration, does not include knowledge of the whole compass of the species, "since no medium can be found between the individuals and the species."[23]

If no such medium exists, then the passage from the individuals to the species, involves a gap between two different orders. It is precisely this gap which abstraction bridges over. From the singulars of the sense world, it disengages the universal notes. Once these are attained, we know in advance that every middle term of the same type (*species*) will embody them. We do not count instances. We analyze them. There is new knowledge and not a sterile process. Our knowledge is such *ut non oporteat ulterius medium quaerere.*[24] Cohen and Nagel write in a similar vein: "Consequently, universal propositions may be safely applied to an actual subject matter only in so far as we are thoroughly familiar with the *type of object* of which the actual case is a *sample.*"[25] Attempted definition of a universal from a mere enumeration of singular cases in which it is found leads to an infinite regress. There is no limit to the number of such individual cases. The infinite series cannot be bridged over by enumeration, so such a definition becomes impossible.[26] When we cannot have definitions, we cannot have science.[27] But the "series," if one may continue

[23] *In Anal. Post.* 1.
[24] *Ibid.*
[25] *Op. cit.*, p. 280-281.
[26] *In I Anal. Post.* 32.
[27] Dantzig cites an example that may seem to validate enumerative induction as applied even to infinite aggregates: ". . . *any mathematical method of demonstration applicable to infinite aggregates is but a complete induction in disguise.* . . . In the words of David Hume, *it rests on our belief that the future will resemble the past,*" *Aspects of Science*, pp. 111-112. This statement describes the procedure of the calculus which is fundamental to the mathematical physics of modern times. But such a procedure is not only inductive. Integration is possible only on the basis of a knowledge of the region that lies between the limits of integration. Hence, Aquinas' argument still holds.

Mathematical induction, even in such rather pure cases as the bi-nomial theorem or determination, by tests, of the convergency or divergency of

to use a mathematical term, *can* be bridged. The method is of a different sort from the empirical. It is the method of abstraction by which the mind passes from sense data to the higher order of intelligible essences.

Physicists overcome, to an extent, the difficulty of traversing the infinite by abstracting facts or laws, relevant to experiments, from their concrete setting. If a test is to be made of the Stefan-Boltzmann law of radiation, which says that the total emitting power of any body is in direct proportion to the fourth power of its absolute temperature, the physicist abstracts from the color of the body, its shape, its atomic and nuclear peculiarities, the time of day, the season of the year, in short from all those circumstances attendant upon the experiment which do not relate to the measurement of radiation and temperature. But even after he has so abstracted subject-matter from its natural context, the physicist is not *empirically* justified on the basis of past experiment to generalize about future ones.[28] On the basis of the logic of the predicables, the reason for this reservation is quite obvious. Aquinas warns against faulty definitions, arising from the improper ordering of an attribute to the subject (e.g., as necessary or contingent when it is really the opposite) and arising from the omission of essential attributes in definition.[29] If we rely on senses alone, we are exposed to both dangers. Aquinas warns also against hasty generalization and equivocation in our search after essences.[30] Reliance on senses alone is to court these two fallacies.

In brief, the laws of physics need a firmer support than the mere enumeration of instances.[31] By the very nature of the sci-

a series, is not wholly inductive. The mind abstracts general relations from the examples induced, and it is not necessary to carry out the calculations beyond the point where such relations can be seen. We are doing what Plato, Aristotle, and Aquinas regarded as a function—doubtless, in the case of Aquinas, the only function—of induction, providing examples for the abstracting of general truths.

The notion of infinity in mathematics is the revenge of the mathematician and the physicist for their failure to reach the unity of form and of being.

[28] Russell, B., *Problems of Philosophy*, pp. 101-102.
[29] *In II Anal. Post.* 14.
[30] *In Anal. Post.* 11.
[31] J. M. Keynes, however, points out the value of enumeration: "The object of increasing the number of instances arises out of the fact that

entific method which confines itself, to use Mill's term, to "the permanent possibilities of sensation," the physicist in his procedure cannot disengage by abstraction the essences of things which authorize necessary and universal judgments. Hence, as a physicist, employing a strictly empirical method, he cannot reach the necessary and universal. But his generalizations, tested and tried by adequate experiment, are not without their necessary and universal character. They derive it from a fact which physics cannot examine, cannot justify or deny. It is the fact of the uniformity of nature.

The question of nature's regularity cannot be settled on empirical grounds. To argue from the conclusions of experiment to their necessity is to beg the question. It is to submit to the full fury of Hume's attack on the principle of causality. It is to accept, on the basis of limited observations, a blind and ineluctable determinism pervading the whole of nature. Such a method cannot be defended on logical grounds. The indeterminism of modern physics becomes an absolute ontal fact if mere experiment is to decide the question of nature's order. Pure empiricism in the mind of the physicist must follow the path of empiricism in philosophy, to rank skepticism and the utter death of science itself.[32]

we are nearly always aware of *some* difference between the instances, and that even where the known difference is insignificant we may suspect, especially when our knowledge of the instances is very incomplete, that there may be more. Every new instance *may* diminish the unessential resemblances between the instances and by introducing new differences increase the Negative Analogy (i.e., the diversity of cases as opposed to their similarity or Positive Analogy). For this reason, and for this reason only, new instances are valuable," *op. cit.*, p. 233. Cf. also Russell, B., *Philosophy*, p. 271.

[32] How can we speak of indeterminism in the microphysical world and determinism in the microphysical one without some standard by which we judge whether a thing is determined or not. The standard is the concept of order. On the basis of the empiricism dictated by his empirical method, the physicist could say that the subatomic world behaves in one way and the molar world in another without being able to say which is determined, or if either is determined. He could not compare the two. Comparison is necessary in judgment, and comparison is only possible when relations are seen. Relations are not formally "given" in the context of experience, as James would hold. They are known when the mind apprehends being, and being is as the bottom of every judgment. As Rousseau remarked, man and the animal differ by the little word *"is."*

Aquinas held firm and fast to an ordered nature. He held it, however, on the basis of a concept that modern scientism has rejected as anthropomorphic—the concept of final causality. *Omne agens agit propter finem.* If every agent did not act toward a determinate end, there would be no reason why one effect should follow from a given action rather than another effect.[33] But there is not only action in the world. There is interaction as well. Not only an order betweeen an individual agent and its individual effect but an order between the individuals themselves which are directed toward one end, God.[34] It is this unifying and coordinating tendency toward God (*assimilari Deo*) which builds the manifold of nature into an ordered hierarchy. Aquinas envisioned nature as the work of the Divine Artist directing all things to determinate ends.[35] Love is the tendency of beings toward their proper ends. Since God is the highest end of all created beings, they are all joined together in seeking their common goal. This tendency of all beings toward one end forms order. Hence, Aquinas says, the world is one, for all beings are ordained by an order toward one goal.[36]

Such in brief is a sketch of the order of nature as Aquinas viewed it. The tendency of things toward their ends he called the laws of nature. Law, he stated, imports direction toward an end.[37] But since scientific technique does not treat the teleological conception of the laws of nature[38] and since, from the point of view of philosophy, it is not possible to detect the intrinsic ends of physical realities of the material world except in a general sense, we are still faced with the problem of justifying the generalizations made by physics on the basis of relatively few particular instances. Scientific method rightly ignores final causality. It cannot be measured. It does not come under the viewpoint of physics, though it is a reality that must be philosophically examined if we are to have a complete account of nature. But if scientific method

[33] *Cont. Gent.* III, 2.
[34] *Cont. Gent.* III, 17.
[35] *In Phy.* II, 14.
[36] *In de Div. Nom.* X, 1.
[37] I-II, 93, 3.
[38] Cf. Planck, M., *Physikalische Rundblicke*, p. 109.

may disregard teleology, we are still confronted with the problem of the type of necessity in the laws which physics finds in the universe. A science may disregard final causality. It cannot disregard necessity if it is to remain a science.

Aquinas argues that a natural cause, when conditions and the effect are not impeded by interference with another cause, will ineluctably produce its effect.[39] But the world of nature is an existential world. There may be the interaction of two causal series which we describe as chance. Such a deviation from nature's uniform course may be due to the material dispositions of the cause itself, to the general material conditions in which the agent acts, or to the material dispositions of the recipient of the action.[40] Matter is a principle of indetermination. Because of its surroundings in the existential world, it may be variously disposed to the form that depends for actualization on the matter's potency. Chance is the stamp of our own ignorance. It is matter subintelligible in itself and hence the source of our ignorance, that accounts ultimately for apparently fortuitous events.

Thus far, the doctrine of Aquinas on efficiency is deterministic. But it is deterministic only on the part of the cause itself as such. It is only a hypothetical determinism or necessity, presupposing the free and unimpeded implementation of the effect. But we must study Aquinas' views on this point in the whole context of his philosophical system. The determinism of the efficient cause is subordinated to the end (*primus inter causas*) of the agent. Aquinas rightly speaks of the realities which are subject to final causality as being of a conditional or consequent necessity—conditioned, that is, by end and following the order it dictates.[41]

All these principles regard not the being of nature but the activities. These are, after all, what the physicist studies. The laws of being, which involve material and formal causality, are absolutely necessary since a thing cannot be otherwise than it is. But the laws of transitive action, which involve efficiency and finality, are necessary only in a qualified sense of the word. They are in

[39] *Cont. Gent.* II, 30.
[40] Cf. note 39.
[41] *In Phy.* II, 15.

the last analysis contingent.[42] They depend on the concurrence of things outside the causes. If an effect depends on factors which are extrinsic to its causes, it cannot claim perfection from its efficient and final causes alone. There may be interference of these factors outside.

Finally, existence in the physical world is itself contingent. The material things may or may not exist. Since physics deals (and can only deal) with the existential world, its laws are always subject to the provision that agents, recipients, and the conditions of action and reception actually exist. This may or may not be the case. Even when it is not, the mere possibility of nonexistence on the part of requisites for transitive action is a sign and source of contingency.[43] In the last analysis, these two sources of contingency—existentiality and materiality—are intimately interwined. Only individuals actually exist in the physical world. They are rendered apt for existence by matter (endowed with quantity)—the principle of individuation. As Cohen says, "This uneliminable character of contingency is but the logical expression of the metaphysical fact of individuality."[44] Individual things alone can be studied by the measuring, sense-dependent technique of modern physics. The individual may or may not exist. Even when existent, it is submitted to the variable potencies of the active, receptive, and conditioning dispositions of the matter which originates it.

As Marling indicates, the doctrine of Aquinas on the order of nature thus steers a middle course between absolute determinism and utter contingency. "As long as form must consort with matter," Marling says, "as long as the universe presupposes individuals, absolute determinism is ruled out and nature's laws are stamped with a provisional character. This does not mean that scientific determinism is ruled out. It merely limits its proper sphere, as after all, science itself must be limited."[45]

But we must seek a sufficient reason for this "scientific determinism" in nature. It cannot be the issue of chance. Chance

[42] I, 82, 1.
[43] *In Phy.* II, 8.
[44] *Reason and Nature*, p. 152.
[45] *The Order of Nature in the Philosophy of St. Thomas Aquinas*, Washington, D. C., 1934, p. 119.

cannot account for the marvellous spectacle of unity in variety that strikes our eyes and amazes our inquiring minds. Even if we grant for argument's sake the indefensible premise that indeterminism, evinced by microphysics, is an objective fact, it is all the more wonderful that this apparent chaos of wave-particle units is marshalled into the ordered cosmos that forms the subject-matter of experience in life and experiment in the laboratory. Between chaos to cosmos, Plato noted, lies a gap that only intelligence can span. Nor can the activities of nature be the immediate effects of the first cause, acting on its own instruments as occasionalism holds. If God endowed material things to seek their natural ends and then stifled their native powers to fulfill their purposes, He would not be all-wise.

The regular recurrence of an effect from a given cause is then not a mark of chance, nor of God's intervention to contravene the ordinary causal sequences of nature. It is a mark of the nature of the cause itself which, not being free, acts in a necessary way. As Joyce writes, "the very concept of a natural agent devoid of free will, involves that, under the same circumstances, its action will always be of the same kind."[46]

We are forced then to the conclusion reached by Aquinas: "The same thing, remaining the same and always in the same conditions, is always bound to do the same and not contrary thing."[47] Or as he also says, the same cause will always produce the same effect, unless something external impedes it.[48] The ultimate roots of the hypothetical necessity of nature's laws go deep into the soil of traditional theodicy, for the search after the causes and reasons of a contingent world must eventually lead back to the Uncaused, Necessary Author of creation. God does not govern His world by freakish interference with the conditions necessary to effect regularly recurring sequences. "On the contrary," says Meehan, *"the conditions are present with a regularity that enables one to reach physical certitude and the presumption that the same order which has been observed in the past will continue in the future is reasonably based upon man's knowledge of both the wisdom and immutability of God, who ordains all things suaviter and firmiter and without caprice."*[49] There is an order in nature based on final causes. But since matter may prove freakish, we must, in speaking about that order, carefully qualify "necessity" with "hypothetical" —hypothetical, that is, in the sense that the order depends on the concurrence of the material conditions outside the final and efficient causes combining to produce an effect.

[46] Joyce, G. H., *Principles of Logic*, London, 1926, p. 237.
[47] *In II de Generatione et Corruptione*, 10.
[48] *In Phy.* II, 14.

It was pointed out above that induction by simple enumeration could not guarantee the distributed middle term which is necessary for demonstration. Every simple enumeration, unless it is complete, suffers from an undistributed middle term; when complete, if we have any means of determining that we have a complete enumeration, it is then a mere vicious circle because the individual case is already known before being "deduced" from the collection. Now the order of nature enables us to overcome both of these difficulties. By the principle of uniformity, we can generalize from the limited range of actual experiments to all possible cases of the phenomena in question. We can then truly make the conversion in the minor premise which, we saw, was proposed by Aristotle to overcome the undistributed middle term. We can also draw conclusions concerning possible experience without becoming involved in the diallela of actually postulating the knowledge of the individual which must be already *formally* included in the premises before we can deduce it as a conclusion. Francis Bacon rightly criticized simple enumeration. But physicists must adopt it, with all of its errors and all of its weaknesses, unless we go beyond the empirical method to a discussion of the non-empirical realities upon which alone genuine physical science can take firm root and be truly scientific.

Scientific laws are only hypothetically necessary. Under the same conditions and in the same circumstances, the same effect will follow the same cause. But our generalizations must be qualified by the fact that since we are dealing with the existential world of material individuals the effect may be impeded. Hume was right in holding that succession cannot guarantee necessity in itself. But there is more than succession in the philosophical analysis of

[49] *Efficient Causality in Aristotle and St. Thomas*, Washington, D. C., 1940, p. 393.

nature's regularity. Ampere's law, Moseley's equation, and the gravitational tensors of the relativity theory will be obeyed whenever the necessary conditions are realized. We know this, not by a merely empirical conclusion based on observed succession in the past, but from an intellectual analysis of the order of nature. Hence we must step beyond the boundaries of physics, if we are to reach a complete and rational account of nature, into a study of the primary substrate and actualizing substance of matter; more importantly must we study efficiency and finality which are the fundamental determinants of nature's activity. Closed off from the world of essences which alone authorize necessary predication, physics nonetheless seeks admission to that world of necessity by a circuitous route. But physics is thwarted in its attempt.[50] It works on a level where the realm of essences is not attainable. So long as this is the case, it is subject to only a provisional necessity no matter how numerous its verifications may have been in the past. So long as it works with individuals which are the antithesis of the universal notes necessary for demonstration, its conclusions are contingent upon the interference, in causal sequences, which makes for deviations. Enumeration, based on inductive division, is, even when supported by a knowledge of nature's uniform course, not sufficient for absolute necessity. Only the abstracting of the specific types or the transcendental notes, contracted in material individuals, can yield the true universal which is such *ut non oporteat ulterius medium quaerere.*

Statistics and indeterminism which express conclusions of physics in the exact language of mathematics do not correct for the contingency of nature's laws. If chance in an otherwise ordered nature is the mark of our *negative* ignorance, probability is the mark of the same fact in a privative sense. In the problems where, in the language of physics, determinism prevails, we have traced the normal curve of nature's behavior which, however, is still subject to contingent circumstances and conditions. Our formulation of causal sequences may be stated in exact mathematics but the sequences will be submitted, when we generalize them into laws, to the sometimes retractable behavior of contingent matter. In

[50] Cf. Thompson, W., *op. cit.*, p. 32.

the case of statistics and of indeterminism, we have not been able to unmask the hidden laws which govern nature, either because the task is empirically impractical or because of the computational difficulties involved. We have introduced a new variable. The laws of probability in statistics or in quantum-mechanical probability-amplitudes, far from correcting for the contingency of the laws of nature have, in reality, added a second—and purely subjective —element of contingency to the objective fact that the activities of nature are contingent on the free and unfettered exercise of efficient causality. The fact that over large aggregates, probability approaches certainty (or in the language of mathematics a 1/1 ratio) and that when we make certain assumptions, as in classical or quantum statistics, correspondingly exact conclusions can be deduced[51]—all this is proof, if proof is needed on this basis, that nature follows a regular course when left to itself and is not a toy of sheer chance, behaving, as the popularizers sometimes say, as though atoms have free will.

The fantastic conclusions drawn from the statistical treatment of the second law of thermodynamics, that water may sometimes freeze on a fire or that a stone may fall upward, are results of the fact that mathematics is the only language which physics knows and that physicists have made it into a universal logic, beyond the expressions of which there can be no legitimate knowledge. They say, to take a rather obvious case, that according to the Bohr correspondence principle quantum mechanics approaches classical mechanics *asymptotically* when particles become numerous and the energy of a system becomes high. But an *asymptote* is a mathematical concept, not a physical one, and to apply it, as it is in mathematics, to physical reality is to follow in the footsteps of Zeno. Macrophysical events in ordinary space obey Newtonian mechanics, as experience attests, and they obey it now as unerringly as similar events observed in the nineteenth century. Physicists have simply discovered in the twentieth century new facts on a different level. They have not denied the *facts,* as facts, discovered by Newtonian physicists and generalized into scientific laws. Such facts are still recognized and treated, classically, by the

[51] Cf. *supra,* p. 47.

contemporary physicist who usually forgets in practice about his asymptote. The human intellect by an abstractive analysis validates this Newtonian treatment of the order expressed in Newtonian physics (as far as this is empirical and factual, i.e., a law in the strict sense). The abstractive analysis is in the light of nature's order. Physicists may claim that Newtonian mechanics is only asymptotically true—because they consider quantum mechanics to be fundamental. But this statement in actual practice becomes purely verbal. It is only theoretically stated because physicists will not accept intellectual analysis which finds a universal order in nature. Such physicists prefer mathematical terminology, although it is scarcely intelligible in this case, even for stating nature's most universal regularities. They do so because mathematics is the only intellectual discipline that they understand in their laboratories and that they recognize when, like Eddington, Jeans, Bridgman, and a host of others, they venture into philosophy.

The same substitution of measurement and of mathematics for abstractive insight and for traditional logic is responsible for the grotesque statements based on thermo dynamics. In modern physics, with its technical, mathematical concepts like that of an *asymptote, limit, infinitesimal,* and mathematical *infinity,* we confine ourselves, if we are treating thermodynamics statistically, to a relatively small distribution and the strictly *mathematical* technique involved in computing the final distribution, from the initial one. In such a case, we may, as far and only in as far as we are dealing with the problem from a rigidly mathematical viewpoint, draw the apparently extreme conclusions that a heated kettle will freeze or that a stone will fall up. If we begin with a probability ratio in mathematics, then we can never end in a one-to-one ratio, even if the original distribution be overwhelmingly in favor of one alternative and if the limits of integration are increased a million-fold or more. This purely mathematical side of the picture motivates the fantastic statements on future probabilities. Observation supplies data for an initial distribution; for reasons already stated we may not be able to measure the individual sample in a precise way, so we have probability equations. The equations are mathematically developed. They are enunciated in general form as though the course of nature could be forecast from the purely

mathematical development of observations in microphysics. Mathematics is the only language which physics speaks. Since a probability ratio in the beginning can, quite naturally, never yield a one-to-one ratio in the end which is what the scientist calls certitude, physicists who adhere to mathematics alone in all their organized thinking, believe that all events must be described in terms of the increasing "disorder" noted in statistical thermodynamics.

But the physical order is not synonymous with the mathematical order. In the universe, there are not only numbers. There are natures. The "disorder" is, like chance, the seal of man's ignorance. If the material entities which seem to be in chaotic movement, obediently to the law of entropy, have no final cause ordaining them to definite ends, there would be no sufficient reason for their action. Such entities could neither act nor exist. They would be contradictory. The "disorder" is a sign of our mind's debility. Being presupposes order. A disordered movement is necessarily repugnant; for if every material being did not have a definite and determined tendency, a definite goal, it would tend in all directions, and no movement would be possible at all. To depart from relatively few observed data in microphysics and then treat them by *mathematical* formulae, as though mathematics could give a complete account of all the activities of nature, is not a logical procedure. True, we could never reach mathematically the 1/1 ratio if we start out with probabilities. But enumeration here is only satisfactory in mathematics as such, and the conclusions cannot be applied to the physical world as such with the pretense that there are no other factors active in nature except the mathematical. If we so apply them, we must bear in mind two points: first, that we are assuming that there is nothing which determines the world of visible experience except the mechanical activities of the microphysical order; and secondly, that we are assuming mathematics to be the complete—and indeed the one and only—reasoned discipline that we apply to the study of matter.

The first assumption explains away the world of quality or form. The second explains away finality or order. But order in nature is not resolvable into mathematics. It can only be studied in its ultimate basis by the intellectual insight, into nature, of the method of philosophy. It is abstraction that bridges the gap, which

enumeration can never get over, between the probability ratios revealed by statistical thermodynamics and the different type of order which is an observed fact in visible experience. All beings act toward definite and determinate goals. To say that a heated kettle of water will freeze or that a stone may fall upward is to overlook finality and make it non-existent simply because it is not amenable to treatment by mathematics. It is to hold that physical observation is the only form of direct *apprehension;* that measurement alone is a meaningful *judgment;* and that mathematical operations are the be-all and end-all of all *discursive* knowledge. It is to deny the validity of abstraction which can proceed above and apart from the probability ratio of an initial distribution of samples that yields mathematically a corresponding probability ratio in the final distribution. In so proceeding, abstraction can analyze material things in the clear light of nature's order, thereby attaining to hypothetical necessity. If we stick to mathematics alone, the physicist is justified in his sometimes weird predictions. But mathematics as the whole story of nature's behavior will never do. *Omne agens agit propter finem.* Final causality may lie beyond the compass of physics and mathematics; but this is a sign of their incompleteness, not a sign of the unreality of final causes. Finally, it may be repeated that probability in the vocabulary of the physicist is not equivalent to *hypothetical necessity* in the vocabulary of traditional philosophy. The former is a sign of our privative ignorance; the latter of our negative ignorance. Deviations from the hypothetical necessity cannot be mathematically forecast; they may affect the exact ratios predicted by the statistical physicist or the probability amplitudes forecast by the Schroedinger equation. In the case of hypothetical necessity we have an objective deficiency, deviations from the normal course of nature. In the cases of statistical mechanics and quantum theory, we have a subjective deficiency, because we are ignorant of nature's normal course in cases of individual phenomena.

Relativity has purported to correct for the errors in measurement made by classical mechanics. Whether it succeeds in doing this is a question for physics, not for philosophy. But here too, the transformations of the restricted theory and the tensor equations of the general theory are subject to the contingent character of the material individuals with which they work. If relativity has improved our measurements of matter, it has not changed matter's ontological status and the consequent contingent character of matter's activity. This contingent character is independent of our logic of measurement, whether it be implemented according to classical, quantum, or relativity mechanics. It is imbedded in matter itself, however it is studied.

On the basis of the hypothetical necessity of the laws of physics and the necessary laws of metaphysics, we can distinguish two kinds of certitude. The former is the firm determination of the intellect to one member of a pair of contradictories because nature, except in very rare and unforeseeable cases, follows a normal course; metaphysical certitude, which holds in metaphysics and mathematics (as pure mathematics), includes no fear of error whatsoever. It is based upon an abstractive knowledge of essences which cannot be otherwise than they are. But physical certitude is not mere probability. It is based upon the order of nature, upon the "scientific determinism" which rules the world of matter—a world where each being tends ineluctably toward a preordained end and where regularity is guaranteed by Divine Wisdom itself. Practically, this state of mind is one of certitude. If the caprices of chance ruled the world and if the only law, to borrow from Rousseau, were that there is no law, God would contradict His Own Intelligence (*sapientis est ordinare*). Moreover, in the universe itself, even the actually observed order in which past predictions have proved reliable would lack a sufficient reason. Lacking this, they would be contradictory.

There is a tendency among modern physicists to reduce all laws to probability and statistics. There is a similar current among modern logicians and such widely different thinkers as Russell and John Maynard Keynes. Keynes writes that "it is generally agreed that an inductive conclusion is only probable, and that its probability increases with the number of instances upon which it is founded."[52] But this statement is very misleading. Statistics is only a logical substitute for an expression of law in individual cases where the law is baffling; it is not an ontal fact which replaces law in individual cases because such a law does not exist.

[52] *Op. cit.*, p. 107.

An induction need not be mathematical. The statement that "an inductive conclusion is only probable" can be met with the answer that both induction and probability may be equivocal. The hypothetical necessity of nature's order is not a mere mathematical probability, as Keynes' doctrine seems to suggest; it is rooted in matter as an *ontal* fact and so is not amenable to *mathematical* treatment. Hence this induction to hypothetical necessity is a logical and not mathematical process, though mathematics may sometimes help to suggest the logical generalization.

Mathematics cannot probe down into the nature of matter where contingency is rooted. It can only predict probabilities when a distribution, and therefore order, is known in advance. In the last analysis then, probability calculations, in the domain where they can be empirically verified, are based not upon the contingency but upon the order of nature. Successful statistical theory must be based on a frequency value. Probability calculus, while expressing conclusions in the language of "contingency" with respect to individual cases, presupposes an ordered distribution. It is a fallacy of the most fundamental and far-reaching importance to our whole reasoned outlook on the universe to confuse the genuine notion of contingency in nature (negative ignorance) and the probability calculations (privative ignorance) of modern physics. The notion of probability in statistics and in quantum mechanics is not based on finality, since the concept of end is rightfully ignored in modern physics as physics and has no place in mathematics; it does not explain chance, since probability calculations in a solution presuppose an initial order from which they were derived; it does not take account of divine intervention which may contravene observed order by impeding the production of effects, as in miracles. The traditional notion of contingency takes account of all three of these factors which are outside the ambit of mathematical physics and which can as much affect the ordered distribution of statistically treated realities or as much affect the probability-amplitudes of the Schroedinger equation as they can contravene the ordinary, non-statistical laws of macroscopic Newtonian physics.

Traditional principles of logic can also be used for a realistic assessment of the method of hypothesis in physics. Knowledge, for instance, must proceed from the known to the unknown. Consequent knowledge must be based on prior knowledge. And the principles must be better known than the conclusions we draw from them.[58] It requires only a cursory glance at modern physics to show that in the method of hypothesis this proper procedure of knowledge, from known to unknown, from premise to conclusion, from more familiar to less familiar, is not observed. Indeed, the opposite seems to hold. A hypothesis is, as we say, a supposed cause. The facts suggest theories. But since a theory is verified by its predictions, the facts are used chiefly to test theories by. A hypothesis is then a leap into the unknown. This fact is apparent from the very suppositional nature of a theory.

The hypothecating type of reasoning employed in modern physics bears analogy to the scholastic causal demonstration, as was already said. This is only an analogy, a hypothesis is not a definition. In the last analysis, it is only an "educated" guess. It is not altogether an *in*duction in the sense of an abstraction. It is, in Comte's language, a *pro*duction of the speculating human mind, i.e., an art. Definition corresponds with the facts that give it birth; a hypothesis, we saw, merely coheres with them. Genuine philosophy may submit that hypotheses be judged by the coherence doctrine of truth. The difference between the coherence and correspondence doctrines of truth is precisely the difference between procession from the unknown to known and the reverse.

A theory may be viewed from two viewpoints which are at least logically distinct: a) theories as interpreting (predicting) phenomena; and b) theories as verified or validated by the phenom- middle term of causal demonstration where the cause, it was seen, is hypothetical, expressing content; it is not the existent essence of strict demonstration. Under the second aspect it must be judged in the light of the principle that by some other theory yet unknown to men the appearances may be saved.

On traditional principles, it may also be asked whether our way of proving hypotheses does not involve an illicit process of the major term. Aquinas and Aristotle point out that appearances may be confused with the essences of things. Thunder, it is said by way of example, is referred to as being a noise in the clouds; but this

[58] For a statement of these three principles, cf. *In I Anal. Post.* 3, 6, 5.

does not express the essence of thunder; there are noises in the heavens which are not thunder. Similarly, we speak of a solar or lunar eclipse as being a privation of light. But not every privation of light is an eclipse.[54] In both cases, one may add, we have reached a cause that is coherent with the effect. But we have not demonstrated the essential relationship between the two. We have not made the distinction between *formal content* and *existent essence*. So long as we rely on the empirical level alone, the appearances themselves can only be saved by appearances. Thought is compelled, as Bradley wrote, to "take the road of indefinite expansion."

Taking these words of Aristotle and Aquinas and applying their principles, though not their facts, to today's problems, we may well inquire whether a given effect now ascribed to one hypothesis may some day prove explainable by another. If that is so, then, our logic in physics has generalized the major term in the process of establishing this theory now in use. It has generalized it beyond the range it had in its premise, and this is at least possible with every hypothesis. It is the illicit process of the major term.

The recent history of science affords ample caution against too great a faith in a single hypothesis as a distributed principle governing the whole range of phenomena in question. The theory behind Newton's principle of gravitation was believed to apply universally before Einstein. Now it is only a special case of the theory of relativity, while the relativity hypothesis itself is believed to be universally distributed. One may also say, in the language of Aristotle and Aquinas, that thunder is only a special case of noises in the clouds and that eclipses are only a special case of the privation of light. Before the advent of quantum theory, scientists were divided on the nature of light. As Bragg expressed it, they used the wave theory three days a week and the particle theory during the rest. Now the two ideas have been welded together in the quantum system. Classical physics had won the universal assent of nineteenth-century physicists, who felt on the whole more confident than their successors today. Now, according to the correspondence principle, classical mechanics is a special case of quantum physics.

[54] *In II Anal. Post.* 17.

Though contemporary physics, despite the efforts of Dirac and others, has not yet succeeded in uniting the mechanics of the quantum and relativity theories, the two may yet be transcended in future studies. The danger that scientific theories may not reach a properly distributed term of demonstration lurks in the failure of scientific technique to reach abstract essences where the range of application is guaranteed by the nature of abstraction and universality. Though we believe our present hypotheses to be true, we may still reserve our unqualified acceptance lest they be restricted at some future date, exactly as the classical theories of the last century. It is provisions against another revolution in physics that motivates what Maritain has called the "delusive purism" of the logical positivists and others of the same spirit. There is, in fact, a contradiction between relativity and quantum theories which shows that one or both must be modified in a most profound way.

Experiment has made rapid strides since the days when Aristotle and Aquinas wrote. By proper variation of conditions in the experiments we conduct, we can eliminate unsatisfactory explanations and more or less verify the satisfactory ones. But even if careful checks may justify a high degree of practical certitude in the value of our theories, the certainty must nevertheless fall short of an absolute category, if only for the reason which Aquinas and Aristotle allege against the explanation of thunder and eclipses, by an illicit process of the major term.

Aquinas elsewhere strikes the weakness in more telling fashion. If the middle term is wider than the major, our reasoning is not valid. For we cannot conclude to one cause when the same effect may be due to several causes, just as we cannot conclude that a person has fever from his rapid pulse.[55] Again it must be kept in mind that modern experimental technique may eliminate the unessential aspects of a given causal sequence as far as our present knowledge goes. But so long as we are ignorant of the true and not merely suppositional relation between the cause and the effect in question, our certitude can never reach absolute proportions but must always be clouded by the possibility, however small or large,

[55] *In I Anal. Post.* 22.

that the effect we observe could spring from a different cause of which we are now ignorant. In this light, Aquinas says that the knower must grasp the "application of the cause to the effect."[56] Then indeed we can have genuinely scientific and certain knowledge. In the reasoning of physics, this requirement cannot be fulfilled in the strict sense because, being ignorant of true causes, we are unable *a fortiori* to grasp them in the productions of their effects.

Demonstration, as we saw, must establish the necessary nexus between a subject and its proper (necessarily inherent) attributes. In the arguments for verifying a hypothesis, this insight into the necessity of the so-called causal sequence is not absolutely guaranteed. Perhaps the subject (theories) is not the proper cause which produces the effect that should be demonstrated by the very definition of this subject itself.[57] Theories by their nature are only tentative. The effects may possibly be explained by another cause. In such a case, the subject is not the proper cause of the attribute or fact that we observe in experience. Hypotheses are conditional causes which are posed to explain effects. They may be elaborated into a precise explanation of a phenomenon or group of phenomena; but the explanation is never absolute because it rests on an assumption.

Analogy plays a fundamental role in the formation of hypotheses. From analysis of sensed phenomena, the scope of a hypothesis can be widened and tested by comparison. Even in the so-called mathematical theories of quantum physics and of relativity, the imagination plays an important role in the process of comparing old data and discovering new ones. Electrical theory is often presented in textbooks by a comparison with a system of hydrodynamics. Einstein employs analogy to explain his general theory of relativity in its physical significance. Maritain has well shown that even the so-called non-Euclidian geometries must revert to the so-called Euclidian space of the imagination to check their conclusions.[58] Otherwise, there is danger that they may lose the consistent character that is the test of their validity.

[56] *In I Anal. Post.* 3.
[57] *In II Anal. Post.* 7.
[58] *Op. cit.*, p. 332.

Boltzmann employed physical analogy in working out his statistical system, and so did his quantum successors who formulated the Einstein-Bose and Fermi-Dirac systems of contemporary statistics. Fourier's so-called mathematical theory of heat flow is based upon a supposed distribution of particles separated by minute intervals and upon physical presuppositions as to the behavior of both. Only after these postulates have been made, as in the case of statistical theory in physics generally, can conclusions be mathematically developed for further application to the physical world. In the Schroedinger equation, the factors H (an operator), E (energy), and Psi (probability amplitude) all trace their origins by however devious a route back to the sense perception of ordinary experience. Analogy is a tool in the service of microphysics: entities, not visible in themselves but known only by their effects, are pictured—or if the word "picture" is unpalatable let us say intuited—by comparison with sense perception to which ultimately they owe their logical origins. Theories in physics must have a physical character. Because they are suppositions, however, we can only know this character, not directly, but by analogy to something which we directly know. True, in the so-called mathematical theories in contemporary physics, the physical background is deemphasized and analogy is played down by the desire to eliminate anthropomorphism. But the analogy is still there in some way. Physics is physical, and the physicist requires an imaginative support to carry out his reasoning about the material world which he studies.

Analogy in this sense is a fruitful source of knowledge in discovery and a ready servant in both teaching and learning, especially in dealing with atomic and subatomic phenomena which elude direct observation. But if it is a good working guide, it is not infallible. "Its strength," writes Stebbing, "depends upon the character of the initial resemblance and upon the relative comprehensiveness of the properties which are asserted to be connected."[59] The problem is to determine whether a deep or purely accidental similarity exists. Here the number of instances has a peculiar role. It is a means of testing analogy because the more we increase the

[59] Stebbing, L. S., *A Modern Introduction to Logic*, p. 253.

instances, the more we are likely to find differences between analogue and analogate, if such differences exist; thus we may correct the initial analogy itself. In this way, we feel safest in predicting when the force of our argument "depends not so much on the number of past experiences upon which we rely, as on the degree in which the circumstances resemble the known circumstances in which the prediction is to take effect."[60]

Modern physics, blessed, as Whitehead remarks, with potent mechanical instruments, can carry out a good check on the essential or merely accidental character of a hypothecated analogy. But there still remains the possibility that another way may be found to "save the facts."

It is analogy in its logical implications which provides the backdrop for interpreting the problem of models and constructs in modern physics. The physicist cannot carry on his work without them. He needs the support which they provide in guiding his thought to new discoveries and in suggesting problems and solutions for his so-called mathematical theories. Yet they need not, and doubtless do not, correspond exactly with the real world. They are not carbon copies. But there has to be a resemblance, even in the midst of differences, between reality and the physicist's *working* construct or model. Only if we admit this resemblance can we find a sufficient reason for the success of physics in predicting phenomena from a consideration of, say, the wave-particle aspects of subatomic entities. We cannot find an exact picture to combine the undulatory and corpuscular aspects of matter and of light. But when the physicist works now with the wave-picture, now with the particle-construct, to guide his thought and suggest new theories and new applications of mathematics, there is in some way a resemblance between the *working* model and the real thing.

Though the analogated entities of the microphysical world seem to tally in some respects with our ideas of what they should be, it does not follow that they correspond to our ideas of what they are in their complete wholes. The present-day physicists, even though some of them take the extreme view in denying resemblances of model and thing and in throwing out models altogether,

[60] Keynes, J., *op. cit.*, p. 241.

are more logical than their nineteenth-century predecessors in this criticism of "mechanical" pictures. Aquinas, at one here with the modern physicist, noted that "it is not necessary for things similar in one respect to be similar in all respects."[61] The criticism by modern physics of the tendency to view models as exact copies of reality is based on incontrovertible logic. There are resemblances between model and thing. But there may also be differences.

Applying the dictum of Aquinas to the baffling problems of present-day quantum and relativistic mechanics, we find that our conclusions concerning the physical bases of modern theories must be carefully restricted. Electrons were found in the Davisson-Germer experiment to obey a wave equation; but this does not mean that electrons are waves: "it is not necessary for things similar in one respect to be similar in all respects." Light rays were found in the solar eclipse of 1919 to be curved; but it cannot be apodictically inferred that the space through which they passed is curved. This principle of Aquinas strikes a nerve center in modern science. Though experiment may aid in throwing out accidental differences between analogue and analogate and in thus reaching more essential resemblances, yet so long as we are reasoning from effect to cause and using analogy to describe the cause, our conclusions must always suffer from the possibility that our conclusions may be defective. There is an obvious danger, then, in concluding from the properties of the analogate to the corresponding properties of the analogue, except for those precise features in which they are found to agree. In the strict logic of demonstration, we cannot conclude that electrons are waves but only that they obey a wave equation. Similarly, we cannot reason immediately from the curvature of light waves to the curvature of space. In the case of the electrons, for instance, our reasoning would be thus: waves obey wave equations; electrons obey wave equations; therefore electrons are waves. Cursory inspection shows that the middle term is not distributed. This formal fallacy characterizes every false analogy.

Finally, the traditional notion of analogy as a method of reasoning provides in physical science a meeting ground for the coher-

[61] *II Anal. Post.* 16.

ence and conformity doctrines of truth, both of which have their place in the assessment of scientific theory. The hypothetical character of a theory involves, as we saw, the coherence doctrine as a formal standard. But as far as there are resemblances, as resemblances there must be, the theories are in a material correspondence with reality. Analogy applies here not only to the so-called "mechanical" but also to the "mathematical" theories of physics. As far as the Schroedinger equation, which is fundamental to modern quantum mechanics, is a theory, it can only be said that it posits a "cause" consistent with "effects." But as far as it works out in practice, it bears at least a *resemblance* to something real, it has some material correspondence with reality, though there may also be the differences which would enable another theory to "save the phenomena."

It has also been pointed out that if we cast the reasoning process of the scientist into the form of a strict hypothetical syllogism, the arguments by which hypotheses are verified involve the formal fallacy of affirming the consequent. "The scientist says, 'If matter is constituted in the way I suppose, then this will be the result; but this is the result; therefore matter is constituted in this way.' There is, of course, the possibility of making the syllogism valid, by making it read, 'Only if matter is constituted in this way.' The difficulty is to justify the 'only.' "[62] The antecedent in a hypothetical proposition can be proved by affirming the consequent only when it is a necessary condition of the consequent. This means, applied to the present problem, that to justify his theories as true the physicist must establish that they are the only ones which can explain (predict) phenomena. Under such harsh restrictions imposed by the very act of correct thinking, the practical certainty which we place in the value of our theories, even the well-established ones, can never attain an absolute status.

Finally, hypotheses are expressed eventually in terms of physical nature; they are also applied to nature. They cannot be considered apart from nature's order. The concepts in a theory represent physical entities and can be reduced to them. These entities are, it was noted, only hypothetically necessary in their activities. It may well be that in modern theories in physics, to use Tennant's significant words, "the intelligibility which science assumes the word to possess and seeks to reveal, is not that of a teleological reasonableness, but rather a quasi-logical rationality."[63] Physics seeks to arrange its concepts with a view to the deduction of facts. But the logical order is dependent on the ontological order as to its origin and to its application.

[62] McWilliams, J. A., "Mathematics and Metaphysics in Science," *The New Scholasticism*, II, 1937, pp. 363-364.

Physicists maintain that the aim of a theory is to predict phenomena. But in view of the contingency of the laws of nature, it is possible that a hypothesis may fail in its forecasting for reasons mentioned in the discussion of cosmic order. Aquinas himself suggests further material for a critical approach to the predictive aspects of scientific theories. He points out that the present, past, and future, which are involved in every temporal sequence, are not in the same genus, and that the passage from one to the other leaves room for the variations in nature's laws. Although the following example can be applied to law as well as theory, it is deserving of special mention here in view of the insistence of contemporary scientists on the predictive function of their hypotheses: It does not follow, Aquinas writes, that because a sick man has taken a certain medicine, he will be cured. Causes which give rise to their effects necessarily are simultaneous with the latter. Here we have a temporal sequence. It is important that the middle term be homogeneous, i.e., of a single genus; if one wishes to establish something from the past, the middle or causal terms should be taken from the past. The same order should be observed in dealing with future things. When, however, it is argued that *this* phenomenon has occurred, therefore we can predict what will follow, the genera are not the same but are related by priority and posteriority (time). Hence, even if the prior conditions are posited, the posterior effects need not follow since effects may be impeded. The words of Aquinas concerning sequence in time can be aptly applied to the predictive aspects of theories in physics. Such a sequence enters into the explanation of the hypothetical necessity of the order of nature. In material beings, which exist and act in time, we cannot guarantee an absolute, inexorable regularity in

[63] Tennant, F., *The Philosophy of Science*, Cambridge, 1932, p. 145.

the course of nature. As Aquinas pointedly declares, from the before to the after, in time, there is no syllogism.[63a]

Such a dictum is in direct contrast to the Laplacian ideal of scientific determinism in which, from a knowledge of a system at one moment of a purely homogeneous time, its states at all future moments are predictable. Modern physics, of course, no longer accepts this view. Though the statements of the physicists sometimes give the impression that this prediction is impossible because the passage from the present to the future is affected by chance and indeterminism, this is not an exact report. Nature is ordered. Chance by its very nature eludes science, even probability-calculations. Our inability to predict the future from the present is not due to the indeterminism of the future in terms of the present but to our ignorance of the present as it is in complete form. Probability and indeterminism are subjective. They lie in the conclusions which we draw only because of the premises which we formulate. Laplace's ideal still holds under the qualification of hypothetical necessity. He erred not in his faith in prediction but in neglecting the fact that our knowledge of the present is inexact. It is our knowledge which is not determined. But even if we reject the view that indeterminism is an objective fact and accept the reality of the hypothetical necessity of nature's order, the predictive value of our theories must always be tempered, even in probability calculations, by the contingency of the causal sequence which Aquinas well summed up in his dictum: *A priori ad posterius non syllogizatur*.

The conditional character of an hypothesis attends upon it everywhere. It is applied to the physical world which exists contingently. Therefore, the beings to which it refers may exist or not, may be impeded or not, in particular cases. We cannot conclude that because a man is healthy, he has taken medicine; but knowing that he was ill and that he took medicine, we can then infer their causal connection.[64] The same conditional qualifications govern our knowledge of the future. We cannot say that a given phenomenon will occur, but only that if it does occur, then a certain causal sequence has taken place. This difficulty merely underscores

[63a] *In II Anal. Post.* 10.
[64] *In II Anal. Post.* 11.

once anew that physics deals with contingent being, i.e., with being that may or may not exist. This hypothetical character of empirical data pervades the theories of physics no less than its laws.

Aquinas' discussion of temporal sequence in relation to logic contains an indirect reference to the fallacy of affirming the consequent. In such a fallacy, the conditioned is mistaken for the absolute. We could not argue thus: If a house has been built, stones have been cut. But stones have been cut; therefore a house has been built.[65] We could not argue thus unless we proved that the building of the house necessarily followed the cutting of the stone. Obviously we could not prove this. The same pitfall threatens our modern scientific theories. Admittedly, Aquinas' example of building a house or curing the sick appears to be rather naive when compared to the elaborate scientific theories that have arisen since his day. But if new and apparently more complicated facts have been discovered, the principles remain the same. Aquinas merely shows in his clear and lucid fashion a truth that might elude us in view of the success of our modern theories: that the affirmation of the antecedent does not follow from the affirmation of the consequent in a hypothetical proposition. To proceed thus to forget that the contingently existing is conditioned by the existence of something else and is not an absolute necessity of being which is independent of temporal sequence and cannot be otherwise than it is.

The foregoing discussion has established the fact that enumerative induction is impossible in practice and that in theory it involves a vicious circle. Hence a pure empiricism is insufficient for genuine science. It was then shown that though scientific laws, because they do not reach essences, cannot in themselves confer necessity for possible experience, they nevertheless can confer a hypothetical necessity in the light of the order of nature. This hypothetical necessity, it was shown, is not the probability equations of statistics and of quantum theory. The indeterminism of wave mechanics does not contravene the order of nature.

In appraising theory, it was observed that hypotheses, not attaining existent essence, involved a "leap into the unknown" and

[65] *Ibid.*

could not guarantee the proper distribution of terms in our efforts to establish a theory as true. As instruments for prediction, hypotheses involve the sequence of time which makes their action subject to the hypothetical necessity prevailing in the course of nature. They also involve a sequence of thought in which the proper order of being can be reversed and the conditional mistaken for the absolute—the fallacy of affirming the consequent.

So far in this work, the method of modern physics as viewed by traditional logic has been exposed and examined. But the philosopher can ask still another question. What is the ontological significance of the physical picture of matter? The answer is necessarily interlaced with the question of method. Method is only a means to an end, and depending on the method we employ is the end we attain. The end of the knowing process should be knowledge. But what is our idea of matter as attained by the empirical method? The question of how the method of physics actually works may now be examined with a view to discovering the general terms in which physics answers the problem of the nature of the existent world. Accordingly, let us take the physical picture of matter, appraising it obediently to the advice of Cicero, "I will follow reason, wherever it leads me."

CHAPTER IX

Atomism, the End of a Frontier

Socrates was not content with a mere picture of the Platonic republic. He wanted, Plato records, to see it in action. So it is with modern physics. If we observe the physicist at work, noting how he proceeds from premise to conclusion, we can best grasp the significance of his method.

Though the concept of the atom, like the word itself, goes back to the Greeks, chiefly Democritus and Epicurus, it was John Dalton in the early nineteenth century who founded modern atomic theory. Reasoning from the fact that chemical substances always combine in proportions (definite and multiple), Dalton arrived at the ideas that: a) elemental substances are made up of tiny individual bodies called atoms: b) all atoms of a given element are alike, having the same weights, but atoms of different elements are different; c) chemical combination of two elements is the synthesis of a small, determinate number of atoms of one element with a small, determinate number of atoms of another element to form each individual particle of the compound.

The discovery by Faraday of the laws of electrolysis—which showed that for each univalent atom there is an electrical charge, or a multiple thereof for a multivalent atom—laid the groundwork for modern subatomic ideas. With the discovery of the electron in 1897 by J. J. Thomson, attention shifted from the description of the macroscopic world in terms of atoms to the resolving of atoms themselves into simpler quantities. On the basis of results obtained by the scattering of X-rays passing through matter, Thomson wrote the next chapter in modern physics: "(1) The atom contains electrons, the number being of the order of magnitude of, but probably smaller than the atomic weight; (2) The neutral atom must contain as much positive electricity as there is negative electricity associated with its negative electrons; (3) The ensemble of the positive charge and negative electrons which make up the atom

must be stable; the electrons, for example, must be held by (electrostatic?) forces in fixed positions of equilibrium about which they may vibrate, when disturbed, with definite frequencies required to explain the characterisic line spectra of the elements; (5) Except when so disturbed, the electrons must be at rest, since, otherwise, they would emit radiation as required by the electromagnetic theory."[1]

The Thomson atom failed to account for the large angle of deflection observed in the scattering of alpha particles (positively charged particles equal in mass to the helium atom and numerically equal in charge to two electrons) emitted from radioactive substances. It became apparent that the alpha particles must encounter forces larger than the Thomson atom was able to explain. To meet this difficulty, Rutherford in an historical article published in 1911 rejected the Thomson idea of the uniform distribution of positive charge throughout the atom. He postulated that: 1) the positive charge must exist in a small region at the center which he called the nucleus; 2) the electrons are held in configuration about the nucleus.[2] Since like charges repel each other while unlike charges attract (Coulomb's law of electrostatics), it was apparent that the electrons were endowed with motion. Moreover, they do not "fall into" the nucleus. Therefore, it was argued, this movement had to be orbital. So the Thomson atom, because of its inability to explain the scattering of alpha particles, was superseded by the Rutherford model in which the positive electrical charge is centered in the mass of the nucleus while the electrons revolve about the nucleus in a way analogous to the planetary motion about the sun.

Rutherford's planetary atom model, though in broad outline it has survived the revolutions in modern atomic physics, was still far from perfect. It was, in fact, in disagreement with the then unquestioned electromagnetic theory which would demand that an electron in circular motion, hence accelerated, emit radiation. This process would result in a loss of energy. The electrons would be

[1] Richtmyer, F. K., *Introduction to Modern Physics*, New York, 1934, p. 349.

[2] *Phil. Mag.*, XXI, 1911, pp. 669-688.

pulled toward the nucleus, continually giving off radiant energy. The spiral movement of the electrons would result eventually in the collapse of the atom. Rutherford's model appeared to correct the Thomson theory. Yet if it obeyed the accepted laws of motion and radiation, it would have made an atom impossible.

Physics thrives on dilemmas. So long as no exceptions can be found to existing theories, the physicist sometimes rests his oars. But once variations are found in experiment, he is spurred anew to action. At the beginning of the present century, the Michelson-Morley experiment, showing that the velocity of light was a constant, stood in direct opposition to classical physics. Out of the conflict came the theory of relativity. At the same time, the radiation of a perfectly black body could not be reduced to classical laws. The dilemma gave to the quantum theory. The quantum theory was extended by Einstein, because of the difficulties of explaining all the phenomena of light on the basis of the wave theory of classical optics. Finally, the duality of matter and light has inspired the theory of wave mechanics. Much of the great work in modern theoretical physics thus bears a resemblance to Hegelian dialectic, in which the opposing views are united into one embracing synthesis, and the coherence theory takes its bow. It was the dilemma facing the Rutherford atom which challenged the world of physics and produced the Bohr theory.

Meanwhile, a new development had taken place which enabled Bohr to formulate his answer. In 1900, Planck worked out an equation for black-body radiation[3] which demanded as a physical basis that the frequency of the energy of emitted and absorbed light have discrete values, multiples of a definite amount. Energy was thus envisioned as being emitted in discrete packets, called quanta. The quantum theory, describing the emission of radiant energy in a discontinuous stream, was at variance with the continuity hypothesis of the classical system. Since, however, physical

[3] This is simply radiation from a perfectly black body. It was studied experimentally in the so-called *Hohlraum*, a spherical cavity having a small aperture permitting the rays of light to enter but not allowing them, after their interplay between the walls, to escape. An absorber, the *Hohlraum* simulates a black body.

theories must stand trial before the jury of experiment, the quantum theory was accepted. A new era in physics was proclaimed.

Einstein vindicated the quantum theory. He was inspired by one of those dilemmas which have become the stimulus of scientific progress toward the analogue what Joachim terms a "significant whole." The photoelectric effect had been a puzzle to physicists. A beam of light causes the emission of electrons from a metal plate at a rate proportional to the intensity of the incident light. To increase the velocity of the emitted electrons, a beam of higher wave frequency, that is of shorter wave length, must be used, even though it may be feebler than the former beam. Until Einstein applied quantum theory to the photoelectric effect, no equation in harmony with experimental evidence had been worked out. Einstein proposed in place of the classical electromagnetic waves that light was emitted in particles called quanta (quants) or photons. On such an assumption a strikingly simple equation could be set up.[4]

The quantum theory was likewise confirmed by the Compton effect. In this phenomenon, a beam of scattering X-rays is found to have two wave lengths, one the same as the original, the other slightly longer. Compton was able to interpret these results in terms of the quantum theory. He supposed that the photon, after colliding with an electron, lost some of its initial energy with the result that it had a lowered frequency when deflected. These now historic interpretations of Einstein and A. H. Compton put quantum theory on a firm basis. The new theory was much more embracing than the old one.

In the light of the quantum theory, Bohr, in 1913, corrected Rutherford's model of atomic structure. Bohr was interested in the problem of spectral lines. They are emitted by substances when excited by thermal agitation or electronic bombardment. The lines are specifically different for each element.[5] To correct the Ruther-

[4] Einstein proposed that each released electron receives just one quantum of incident energy and that the energy of this electron is equal to the energy of the incident quantum minus the work done in dislodging the electron from the atomic configuration. Surprisingly simple, this equation of Einstein has been experimentally verified.

[5] Physics is able to differentiate one element from another by spectroscopy.

ford atom model in which the accelerated electrons obedient to electromagnetic laws should constantly radiate energy, he proposed two important postulates: 1) For every electron there is a limited number of orbits in which it does not radiate but is stable; the energy of an electron in such an orbit is anchored to a certain energy level and is said to be in a stationary state; 2) when an electron rises from a lower orbit to a higher one, it absorbs energy; when it falls back again, it descends to a lower level and the lost energy is emitted as radiation.[6] Bohr's theory proposed that the orbits and the angular momentum of an electron had discrete instead of continuously variable values. He called this interrupted character of mensurable matter *quantization*. It was another development of the quantum theory.

From his mathematical interpretations, Bohr was able to deduce the so-called Rydberg constant, found experimentally in spectroscopy. This constant occurs in equations for lines in the hydrogen spectrum. It became a relatively simple task now to derive on theoretical grounds the mathematical statement, hitherto empirically known, of the Lyman, Balmer, and Paschen series of lines for hydrogen. The normal orbit of hydrogen's solitary electron is 1. In falling into orbit 1 from orbits 2, 3, and 4, it was computed, lines of the so-called Lyman series appear. In dropping into orbit 2, the so-called Balmer lines appear. And so on. Bohr's theory passed the test of physics. It agreed with experiment, could predict its results.

The motion of a particle of sufficiently small kinetic energy and under the influence of a central force traces in general an elliptical curve. Sommerfeld extended the Bohr theory to ellipses. Making corrections demanded by the theory of relativity (in which mass varies with velocity), he was able to calculate the differences in energy between the various elliptical orbits.

Bohr's mathematical simplifications make it impossible to apply the theory to larger atoms because of the mathematical complexity of the many-body problem. Then too contemporary physics has come to believe that the laws governing subatomic phenomena are so different from those of the macroscopic world that it is no

[6] Ruark and Urey, *op. cit.*, p. 14.

longer possible to think of atoms in terms of a mechanical model. But the Bohr theory has been so fruitful, especially in simpler atoms, that its usefulness has not been completely outlived. Its fundamental concept, of energy levels and of the emission of photons when electrons drop down toward the nucleus from their higher orbits, remains fairly firmly established in modern physics. References will be made further on in this chapter to later developments of quantum theory. After the foregoing description of the Rutherford-Bohr atom model, it is necessary to continue with an outline of the fundamental units of the material world as viewed by the contemporary physicist.

The nucleus of the hydrogen atom, bearing a positive charge sufficient to equalize the negative charge of one electron, has been called the proton. Two new facts, discovered in very recent times, have raised problems as to the nature and number of particles in the atom. Until the early 1930's, the atom had been regarded as a composite of a nucleus, in which the protons outnumbered the electrons, and an orbital configuration of electrons in just the right number to neutralize the excess positive nuclear charge. In 1932, Anderson, after a cosmic-ray bombardment of a piece of lead, obtained a photograph of tracks which could only be interpreted as the paths of positive electrons or so-called positrons. Subsequent photographs indicated that the release of positrons under the impact of high-velocity cosmic rays was no rare phenomenon. Physicists began to speculate about the place of the positron in the subatomic world.[7]

In 1934, Chadwick showed that the difficult problem of accounting for the high penetrating power of rays produced when alpha particles (from polonium) bombard certain light elements like beryllium, boron, and lithium, could be solved on the assumption that the high-powered alpha rays disrupted the atom's nucleus and released a particle having a mass but no charge. This particle became known as the neutron.[8]

The exact relations of the positron, the proton, and the neutron have not thus far been accurately traced. A proton has been believed to yield, on disintegration, a neutron plus a positive electron (positron) ; a neutron yields a proton plus a negative electron. But these disintegration equations have not yet been accepted as final. As Lindsay and Margenau write, "The view seems current among physicists that, of the proton and the neutron, one is elementary and the other complex. But whether the proton is a neutron combined with a positron, or whether the neutron is a proton combined with an electron is a much debated question."[9]

[7] *Phys. Rev.*, vol. 43, p. 491.
[8] *Proc. Royal Soc.*, London, vol. 136, p. 692.

In beta-ray radiation, emitted electrons are found to vary in energy. The spectrum runs from zero up to a certain maximum of electron volts. The resulting curve for energy distribution against frequency, in contrast to a similar curve for alpha particles, seems at variance with the law of the conservation of energy. Energy seems to have been lost. Suggestions have been made, by Dirac among others, that the law of conservation does not hold in the case of the continuous beta-ray spectrum. However, this view has not been generally accepted. To solve the problem and to preserve the law of conservation, a particle called the neutrino, having energy but a very small mass, has been postulated.[10] On this view, whenever an element loses a beta-particle, it also loses a neutrino. In such an explanation, the law of energy conservation holds true. Tuve has referred to the neutrino as a name that we have invented for lost energy.[11]

The disintegration of atoms has been known since the discovery of radioactivity. Radium, for instance, emits, among other rays, the so-called alpha-particles. Each of these is a helium nucleus, combining with two electrons to form an atom of helium. The residual atom, radon, is also radioactive. It breaks down progressively into different atoms, either isotopes of the preceding atom in the disintegration series or an atom of a different atomic number. With the loss of each succeeding alpha-particle there is

[9] *Op. cit.*, p. 513.
[10] *Royal Soc. Proc.* 161 A, pp. 447-460, Aug. 20, 1937.
[11] The neutretto, "a neutral particle with the same mass and other similar properties as the heavy electron," has been postulated to account for the "fact that the forces between two protons seem to be equal to those between a proton and a neutron," *Nature*, vol. 142, p. 157.

a new isotope or new element. The end product of the radium series is an atom of lead.

These facts suggest the picture of the atom accepted by modern physics. Differences in elements are the results of the number of electrons and protons which the atoms contain. For physics, differences are additive, not formal. They are numerical, not substantial. Diversity of property and activity is a function of the number of particles that constitute the atom, more precisely the number of nuclear particles, since these determine ultimately the electronic phenomena.

Physics believes to have verified its additive concept of differences in the fact of atom-smashing. By means of the van der Graff generator, extremely high electrical potentials can be developed. With this voltage, positive ions are accelerated until they have sufficiently high energy to penetrate to the nucleus of a bombarded atom and there to dislodge nuclear particles. The cyclotron accelerates positive ions by driving them in circular paths instead of the linear ones used in the van der Graff machine. By means of a strong electromagnet, the ions may be accelerated a great number of times using relatively low voltages. When energized sufficiently to pierce an atomic nucleus, the ions are released against the target atoms. In the phenomenon of atom-smashing, the loss of every proton, for instance, brings a corresponding release of an electron from the extra-nuclear region. The new atom, with a different constitution and different physical and chemical properties, moves lower down in the periodic table in the same way as the transmuted elements in the natural, radioactive series of disintegration. In accounting for differences in elements, physics is true to its atomizing method.

Atomic physics took a new turn in recent years. If we wish to trace the present status of the science, we must now follow it along the astonishing highway that leads to wave mechanics.

The nineteenth century had abandoned Newton's corpuscular theory of light. It had accepted the undulatory theory of Huygens because a wave hypothesis was better able to explain experimental data. The phenomenon of interference—the alternate light and dark bands produced when a single beam of light passes through

two pin-holes and is then observed on a screen—was believed explainable only in a wave vocabulary. Two systems of waves, meeting in opposite phases—when the crests of one system correspond with the troughs of the other—neutralize each other (the dark band). Waves in the same phases—where the crests of the two systems occur together—reinforce each other (the light band).[12] Fresnel interpreted diffraction rings, the alternate light and dark bands in shadows, in a similar way, as a phenomenon of interference. The wave theory of light, chiefly because it could account for these two phenomena, interference and diffraction, thus went almost unquestioned throughout the nineteenth century.

But while radiant energy was conceived as waves, the physics of matter was always interpreted on an atomic basis. The atomic hypothesis of Dalton, the kinetic molecular theory, and finally the atomic hypothesis of the constitution of electricity divided physics into two apparently unrelated systems, that of radiation based on waves and that of matter based on particles. Matter and energy were two separate phenomena. The early quantum theory complicated the problem even more. It revived the corpuscular theory of light. But it failed to explain interference and diffraction. So physics had a two-front conflict in which there was not only a rift between the physics of radiation and the physics of matter but a fundamental conflict within the study of radiation itself. It was another of the dilemmas which head the great chapters of contemporary physics.

In 1925, de Broglie announced a wave theory of matter. In reaching the idea of so-called matter waves, which has gone far to remove the old antinomies in atomic physics and unify it as a branch of knowledge, de Broglie reasoned that since whole numbers were associated with interference and vibrations in general it was necessary that the electron also, because it would be represented by whole numbers, have a periodic property.[13] De Broglie was also impressed by the parallelism between Maupertuis' principle of least action in particle phenomena and Fermat's principle,

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[12] Wood, R. W., *Physical Optics*, New York, 1934, pp. 157 ff.
[13] de Broglie, L., *op. cit.*, p. 185.

in radiation, of least time.[14] Such considerations led him to the bold conclusion that just as light exhibits wave and corpuscular properties, so matter may be said to have a dual nature. He then set out to find a suitable mathematical expression for his conclusion. He reached the formula that for an electron with mass m and velocity v, the division of Planck's constant h by the electron's momentum mu yields the wave length associated with a stream of electrons.[15]

Up to this point, de Broglie's novel idea remained a mere speculation. What was lacking was the circumstantial evidence for the physicist's court, experiment. The American physicists, Davisson and Germer, finally supplied proof of de Broglie's idea. They performed an experiment which confirmed the wave hypothesis. They bombarded the surface of a nickel crystal with a low-voltage electron-gun, measuring the deflected electrons by means of a "collector" having a very small aperture.[16] Their data agreed with de Broglie's equation. The theory was subsequently confirmed anew in the work of Kukuchi and Rupp who obtained photographs of diffraction bands that resembled the interference rings noted a century earlier in classical optics.

But what is the physical significance of the electron-waves? There are several possible interpretations as de Broglie himself observes.[17] Schroedinger, author of a mathematical theory that has done much to perfect the theory of wave mechanics, had advanced the idea that an electron is made up of a group of waves. Another hypothesis is that the particle is a singular factor in a larger undulatory phenomenon. Kennard has advanced the idea that the whole problem can be avoided if, instead of employing the terms *motion* and *trajectory*, we merely resort to the abstract expression, *probability elements*, to cover both. Finally, there are

[14] The principle of least action states that of all the possible paths between two points for constant energy, a projectile will follow the path which makes the "action" a minimum as compared with its value for any other length. Fermat's principle states that a ray of light, passing between two points, will take the path requiring the least time.

[15] *Op. cit.*, p. 201.

[16] *Phys. Rev.*, vol. 30, p. 707.

[17] *Op. cit.*, pp. 204-205.

the views of Heisenberg and Bohr that since the matter-waves are not to be thought of in the ordinary physical sense of the term *wave*, the conception of wave is merely a symbolical representation of our knowledge of the particle. According to the Heisenberg principle, the velocity (momentum) and position of a particle cannot be computed simultaneously. In practical problems of atomic physics where energy is of great importance, matter is thought of in terms of particles; and where position is of major interest, the concept of wave comes to the fore.

In the views of Heisenberg and Bohr, wave and particle properties are not opposed but complementary. If we wish to study particle properties, then we cannot observe the wave properties simultaneously and *vice versa;* we cannot detect the particle properties in an experiment designed to study electrons as waves. The Heisenberg principle is thus especially fruitful in supporting what Bohr has called the Principle of Complementarity.[18] On this point, Schroedinger has written: "One may believe either (1) that matter has *really* a wave structure. Then the uncertainty principle is an immediate consequence. Or (2) one may think that the uncertainty principle is more fundamental. The wave theory then is simply an auxiliary construction for the convenience of grasping and representing the principle."[19] According to the Principle of Complementarity, wave and particle properties are not contradictory. They represent two different ways of looking at a reality which we can never study experimentally as it is in its ontal whole. We can never study it thus because according to the principle of indeterminacy our measurements interfere with the phenomenon we have set out to study. By the very conditions of experiment, as the Heisenberg principle says, we can study reality only in its parts and can never reach empirically the real relations which the parts bear to each other in ontal combination.[20]

[18] *Naturwissenschaften*, vol. 16, p. 245; *Nature*, vol. 121, p. 580.

[19] *Op. cit.*, pp. 162-163; Frank, P., *Interpretations and Misinterpretations of Modern Physics*, pp. 14-15.

[20] "Perhaps the best description can be made by the use of a commercial expression; an electron is a particle 'and/or' a wave. We must be ready all the time to think of it as either or both, but we must not mix the ideas. There are two half-worlds, each of which gives a partial view of the whole

The mathematics of wave mechanics, as developed by Schroedinger, Dirac, Heisenberg, Jordan, and Born, does not propose to mold a model of reality. The language of physics has become more and more abstract and abstruse in its symbolic figures and their combinations. Physics now speaks of wave- or psi-functions as "probabilities" and particles as "probability-packets." It apparently abandons its attempt to trace out the physical counterparts of its language which become lost in what has been called the "shadowy jungle" of indeterminism. Classical physics is only an approximation to reality. It is satisfactory for practical purposes, when energy is large and velocities are low. But it is not theoretically correct.[21]

The use of the Schroedinger equation to provide accurate prediction for large aggregates of particles and the concept of the statistical method, especially that of the Fermi-Dirac system, may suggest that physics is abandoning its atomizing method, is thinking instead, in terms of wholes. But this is by no means the case. We are dealing here with quantitative "wholes," with sums. The whole is still regarded as being determined by its partitive proc-

world: they are related to one another and interdependent, but they are expressed in different languages. We call the two half-worlds the 'particle-aspect' and the 'wave aspect,'" Darwin, C. G., *New Conceptions of Matter*, New York, 1931, p. 96.

[21] This is a physical interpretation of the Bohr correspondence principle. Strictly speaking, it is representable by tracing the energy curves on the basis of quantum mechanics. "We may assume, however, that if we go to a very high quantum number, so that we are far out on the axis of the abscissas, any ordinary energy curve will become asymptotically fairly smooth and straight, so that the chord and the tangent to the curve will more and more nearly coincide," Slater and Frank, *Introduction to Theoretical Physics*, New York, 1933, p. 361.

The mathematical description of the correspondence principle given above merely means that as the energy increases in a low-energy system quantum mechanics will approach classical mechanics and become, for practical purposes, equivalent to it. An asymptote of a curve is a concept of analytic geometry. It means "a straight line which the curve approaches indefinitely near as its tracing point passes off to infinity," Smith, Gale, Neeley, *New Analytic Geometry*, New York, 1928, p. 39. A similar reasoning can be applied to the Theory of Relativity which applies only to systems in which the velocity approaches that of light. As these high velocities decrease, Relativity mechanics approaches the classical system asymptotically.

esses.[22] These individual units cannot be accurately measured because of the Heisenberg principle and because of additional experimental and computational complexities which a measuring procedure would involve.[23] But they and they alone determine the collection.

Thus far in the outline of the atomizing tendencies in modern physics, no mention has been made of the factors which hold the particle-waves together. Physics tends to reduce reality to categories of number and measure. "Man" for example, means for the physicist a mere assembly of measurable quantities or quantum states. So does iron, copper, or any other substance. But if reality is conceived as a mere lattice-work of microscopic units, the physicist is none the less confronted by the problem of the coherence of the atom in a stable configuration and the binding of the atoms themselves into molecules. This problem is solved in a manner analogous to that in the problem of structure—by supposing the existence of mechanical (or quasi-mechanical) forces which cement the parts.

A fundamental principle invoked to explain the coherence of the atom into a system is the law of electrostatics that like charges repel each other while unlike charges attract. In this way, positive and negative electrical units are conjugated into a stable configuration which is electrically neutral. Though physics holds that the electrons are endowed with kinetic energy of motion, the electrical nature of the atomic phenomena, on well-founded evidence, is even more fundamental than its motor properties. In order to explain the effect of a magnetic field on spectral lines emitted by an atom, it was necessary to postulate that associated with the electron is a magnetic field produced by its rotation (electron-spin). The Stern-Gerlach experiment, a study of an atom's behavior in a magnetic field, had shown, before the advent of the spin-hypothesis, that the atom had magnetic properties. The electromagnetic forces within the atom are quite basic, if indeed they are not the fundamental dynamic elements in our present picture of the atom. It is

[22] Tolman, R. C., *op. cit.*, pp. 43 ff.

[23] Darrow, K. K., "Statistical Theories of Matter, Radiation, and Electricity," *Phys. Rev.*, vol. 1, pp. 90-155.

difficult to speak of picturable phenomena in contemporary physics. "Yet in the picture of the universe as now presented," Darrow writes, "there are particles possessed of charge and mass; there are electromagnetic forces between the particles; there is radiation . . .; and outside of the realm of "nuclear" phenomena there is nothing else. The stability of the world, that is to say, of the picture, is assured by the attractions and repulsions, electrical in nature, and by motion, with radiation playing an essential part."[24]

But the question of the coherence of the atom is not only one of keeping the particles together. Since there is an excess of positively charged particles in the nucleus, why do they not repel each other, exploding the atom by the sheer force of electrostatic repulsion? Here one finds the central problem in modern atomic physics—the problem of the nucleus. The cohesion of the positively charged particles is the result of so-called "exchange forces." This is a quantum-mechanical concept. It has no classical analogue. Depending on the behavior of the given wave functions to an interchange of electrons, it is possible to calculate whether this exchange force will keep the particles together or drive them apart. As used in physics, the term "exchange force" lends itself much more readily to mathematical description than to a physical picture. Darrow states the problem of intra-nuclear attraction and repulsion in summary fashion: "It is possible . . . to compare the amount of energy required for tearing apart a cluster of two protons and a neutron with that required for tearing apart a cluster of two neutrons and one proton. The two amounts differ by only a few percent; and more surprisingly, yet, the former is the greater! Though the first-named of the clusters contains the inherent explosive power of two protons trying to drive themselves apart by long-range repulsion, it is stuck tighter together than the other which contains nothing of the sort. As a minor detail, this shows that the cohesive forces depend to some extent on whether the particles are neutrons or protons; but the major conclusion is, that the cohesive forces are the masters."[25]

[24] Forces and Atoms: The World of the Physicist," *The Bell System Technical Journal*, vol. 20, p. 348.
[25] Darrow, K., *art. cit.*, p. 352.

One of the most promising of recent suggestions in nuclear physics is the "meson theory." The meson, the heavy electron found experimentally thus far only in cosmic radiation, has been advanced by Yukawa and others as associated with the binding fields of nuclear particles, probably giving rise to the exchange forces themselves. Whether the so-called nuclear meson is the negative particle of cosmic radiation or whether it is neutral in charge is not a matter of agreement. However, future theoretical developments may be expected with regard to the meson theory,[26] or some other such particle (i.e., partitive and mechanical) theory of atomic binding energies. Apart from its present significance, the meson theory is thus a powerful suggestion that energy is 'substantialized' in physics, i.e., is viewed like matter to be particle-units.

The role of gravity in subatomic phenomena is too small to be appreciable in its effects. There is, however, a very important quantum-mechanical principle which plays a fundamental role in particle interaction. It is the Pauli "exclusion principle" which states that no two electrons can have exactly the same states of motion (quantum numbers). This is a repulsive force acting between similar articles. Its reason for existence is not known, but it may some day be deduced from a more general hypothesis.[27] From the Pauli principle, the periodic system of the chemical elements can be built up in deductive fashion. It has also been fruitful, with reference to the repulsive actions of electrons on each other, by providing helps for computing the probability-distributions of the four co-ordinates (or quantum numbers) of electrons.

The energy required to release a particle from an atomic configuration is called the binding energy of that particle. A philosopher may ask the question: what is energy? The physicist would define it in his mathematical language as "the space integral of the force acting on the particle."[28] But the philosopher, holding that physics is physical and has to have an empirical something to measure, must ask about the concept of energy in a *physical* sense.

[26] For a discussion of early and pre-war meson theory, cf. Bethe, H., *Phys. Rev.*, 57 (1940), pp. 260-272.
[27] Lindsay and Margenau, *op. cit.*, p. 121.
[28] *Ibid.*, p. 121.

According to the theory of relativity, energy itself has mass. The decrement in mass observed in nuclear reactions is found to be exactly equal to that which corresponds, relativistically, to the released kinetic energy. According to the theory of relativity, matter and energy are therefore considered as equivalent.

In speaking of electrical energy, Millikan writes that, "when we combine the discovery that an electrical charge possesses the distinguishing property of matter, namely, inertia, with the discovery that all electrical charges are built up out of specks all alike in charge, we have made it entirely legitimate to consider an electric current as the passage of a definite, material granular substance along the conductor. In other words, the two entities which the nineteenth century tried to keep distinct, begin to look like different aspects of one and the same thing."[29] In a similar vein, it may be noted that the most recent treatment of the problem of electrical conduction tends to regard it as a phenomenon of an "electron gas." This postulate is employed in the Fermi-Dirac statistics. "It involves," Darrow writes, "the volume V which the assemblage of particles pervades. For this we set the volume of the piece of metal—a decision which is tantamount to ignoring the atoms, to supposing the metal in a vacuum inhabited by free electrons only."[30] In its attitude toward energy, physics bears testimony to its views of the structure of matter as purely partitive. Rougier speaks of physics as having achieved in the quantum theory and in the theory of relativity "the materialization of energy."[31] This is a parallel of Millikan's opinion that energy is substantialized in scientific method. Energy has mass, inertia, and even structure; matter is regarded in terms of waves and fields.

The field concept of the general theory of relativity becomes, when it is considered no longer as an *empirical* hypothesis for measurement but as an *ontology* of matter, a system of dynamism like the energetism of Ostwald. "Matter is where the concentration of energy is great; fields where the concentration of energy

[29] *Electrons (+ and −), Protons, Photons, Neutrons, and Cosmic Rays,* Chicago, 1935, p. 168.
[30] "Statistical Theories of Matter, Radiation, Electricity," p. 115.
[31] *La Matière et l'Enérgie,* Paris, 1921, p. xi.

is small."[32] Matter is in itself not the fundamental stuff it was thought to be by classical physics. It is a phenomenon of field. It is concentrated energy. A complete and consistent field theory has not been worked out. Even in the attempts—by men like Weyl and Mie—to unite gravitational and electromagnetic fields into a single system, there are lacunae. In spite of the failures, the aim of relativity physics is to elaborate a field-concept for the explanation of all phenomena.[33]

The restricted theory of relativity denied the existence of ether as an unobservable. The general theory restores it in new form. It becomes not a medium but the very stuff of the universe. It constitutes the space-time continuum which is the fundamental reality. Relativity may be said to geometrize the real, in a way that approaches the ideal of Descartes: the reduction of matter to extension. The fundamental science is world-geometry. A phenomenon is accounted for when its properties can be expressed in the geometry of the four dimensional manifold. But in another sense, the concept of material things in the general theory of relativity is not Cartesian. It is dynamistic like the monadology of Leibniz. It is the field, not matter, which is fundamental.

The field theory is not atomic. But it is partitive in the dynamistic sense of conceiving structure as a composite of divisible point-events expressible in world geometry. In the second place, it is not, in contemporary physics, the fundamental science of structure in the material world, at least in a verifiable sense. If the physicist is asked to determine the make-up of matter, he can only perform the task by empirical means. When he begins to experiment, he encounters the problem of the Heisenberg principle which contradicts the theory of relativity. In this point one finds the reason why quantum theory in its present form, despite the efforts of Dirac and others, cannot reach a meeting-ground with the theory of relativity. According to Einstein's hypothesis, a material entity is specified by space-time. In the quantum theory, position (space) and velocity (time) can never be specified simultane-

[32] Einstein, A., and Infeld, L., *The Evolution of Physics,* New York, 1932, p. 257.
[33] Weyl, H., *Raum, Zeit, Materie,* Berlin, 1923, p. 216.

ously. The simultaneous determination of these two co-ordinates has no meaning in quantum mechanics. In the theory of relativity, it is the most meaningful statement that can be made. Quantum mechanics has the upper hand today. We seek to determine experimentally what the world is made of. Experiment is the only standard which physics can employ. So we break up reality, and as we proceed with this process into the subatomic field, relativity loses its meaning. The profundity of this conflict should make us especially wary of accepting as final either quantum theory or relativity.

De Broglie has suggested that wave mechanics provides a means for overcoming the age-old conflict in physics between continuity and discontinuity.[84] Can matter-waves, like light waves, conjugate to form a continuum? The answer depends on our concept of waves both in matter and light. De Broglie suggests an answer based on wave mechanics. The existence of such a continuum, he points out, cannot be rigorously determined because of the Heisenberg principle. Because of this indeterminacy factor, one can only make successive and discontinuous measurements that result in probability values but never in a definite answer. Thus, the theory of wave-mechanics which pacified the conflict between matter and light may, if we may believe one of its leading spirits, also synthesize the continuum and discontinuum in modern physics.

But the continuum suggested by de Broglie is still only an aggregate. It is a sum, not a formal whole. The totality is reducible to the parts that make it up—reducible that is in a non-empirical sense because, practically, the principle of indeterminism impedes exact measurements. A similar answer may be given to the statement that whether the protons and neutrons retain their identity in the nucleus, "or whether they melt into a composite mass surrounded by an electron-neutrino atmosphere is not clear from general arguments."[85] A "composite mass" might well exist in

[84] "Physique Ponctuelle et Physique du Champ," in *Revue de Métaphysique et Morale*, v. 45, p. 331.

[85] Breit, "Some Recent Progress in the Understanding of Atomic Physics," *Rev. Scientific Instr.*, vol. 9, p. 65.

this sense. But how does the physicist account for it? He reduces it to parts and then adds the parts together to make the whole.

The purpose of this chapter was to pass in review the present tendencies in physics toward the study of matter. New discoveries will be made in the immediate future. They are being made at this moment. They will add new facts to the picture of the world as the physicist paints it. They will not alter the general approach of physics. Nor will they force any changes in the philosophy of this method. They will only show further the atomizing method of modern physics which Planck has well described in the words, *Divide et impera.*

CHAPTER X

Beyond the Frontiers

It was fashionable up to very recent times to consider the atom as a miniature planetary system in which the orbital electrons revolved about a "nuclear" sun. This figure still applies, *mutatis mutandis*, even to the atom of wave mechanics. The component particles may not be exactly measurable. But physics tends to consider a material thing as a composite of disparate parts like the bodies of the solar system. The parts are held together by mechanical forces.[1]

The protest of Dirac that quantum mechanics is able "to give an absolute meaning to size"[2] does not employ the word *absolute* in the strict sense. "We may define an object to be big," he writes, "when the disturbances accompanying our observation of it may be neglected, and small when the disturbances cannot be neglected."[3] But this so-styled absolute meaning of size is in reality relative to our measuring instruments. Hence it is not truly absolute. With particle-guns operated by ever higher and higher voltages, it is possible that the units now considered ultimate may themselves be divided. It is entirely in the direction of the present method of physics that electron-, neutron-, and proton-smashers may replace the atom-smashers in use today.[4] It is true that it

[1] "The state of a physical system cannot well be otherwise defined than as the aggregate of all those physical quantities; through whose instantaneous values the time changes of the quantities, within given boundary conditions, are uniquely determined," Planck, M., *Eight Lectures on Theoretical Physics*, New York, 1915, p. 48.

[2] *The Principles of Quantum Mechanics*, p. 3.

[3] *Ibid.*, p. 4.

[4] "It may happen that further experiment will enable us to determine which of the various hypotheses corresponds to concrete reality. Such, indeed, was the hope of the scientists of the eighteenth and early nineteenth centuries. And in our days the practical isolation of electrons and molecules is a proof that these hopes were not always unfounded. Yet, even so, we

may be impractical to build instruments that will continue to divide matter indefinitely. Indeed with present-day facilities, attempts to divide the electron have been brought to failure.[5] But this does not mean that matter is not indefinitely divisible.[6] As d'Abro has stated the paradox of physics, if the supposedly ultimate elements had no structure, we could not study them empirically; if they had structure, then they would not be ultimate but divisible.[4] Indeed, the atomizing method implies in its own way the indefinite regress into smaller and smaller particles and the forces holding them together.

As it was noted in the foregoing chapter, not only in dealing with the entitative character of structure is science atomistic. Its whole treatment of dynamic phenomena is in parallel. Electrostatic attraction between proton and neutron holds the atom together. Exchange-forces keep the nucleus from exploding. The interplay of electrons between orbits accounts for radiation, according to the Bohr theory; motion and the theory of stationary states keeps the atom from collapsing. The spin-hypothesis accounts for certain spectroscopic phenomena. The neutrino helps to explain the continuity in the beta-ray spectrum. The Pauli exclusion principle accounts for certain variations in state as represented by the mathematics of wave-mechanics. Gravity helps to explain attraction. The concept of energy as possessing mass ac-

should have advanced but a step and should again be faced with the problem of determining the structure of these electrons, and so *ad infinitum*. It would be of no avail to say that *our* aim had been realized when the ultimate constituent elements were isolated. For either these supposedly ultimate elements would have no structure, in which case we could never know anything further about them, or else they would present a structure; but then they would not constitute ultimate elements, since this structure would imply relationships between their various parts, and we should not be at the end of our journey," d'Abro, A., *Evolution of Scientific Thought from Newton to Einstein*, p. 402.

[5] Millikan, R. A., *op. cit.*, p. 161 ff.

[6] "It appears then that present experimental evidence makes very probable structures beyond the electron and the quantum; we may even go further and say that there is no experimental evidence that the sequence of phenomena in nature as we go to ever smaller scales is not in itself essentially infinite," Bridgman, P., *The Logic of Modern Physics*, p. 207.

counts for the decrement of mass in certain nuclear reactions. The concept of light as a wave explains the phenomena of interference and diffraction. The concept of light as corpuscular explains the photoelectric phenomenon and the Compton effect. The same duality is employed in the treatment of matter by quantum mechanics. In its analysis of matter, physics stops at atomistic *ad hoc* explanations. Even if they possess a species of unity like that of "content," they are only provisional accounts that can be altered, like the concept of ultimate particle, as physics proceeds further and further in dissecting matter. "It is the essence of the whole quantum theory that *'ad hoc'* explanations are made, *ad libitum*, where such assumptions serve a useful purpose."[7]

Such a system of concepts is not to be condemned as a scientific technique. It is the only method possible in a science that seeks after content and systematization. It has been a fruitful source of progress in both a theoretical and practical sense. The achievements of modern science are one of the wonders of the ages. But in philosophy, we must recognize physics for what it is. It is by no means a stigma that science employs a series of *ad hoc* explanations for phenomena that a philosopher, with a different purpose, would regard under a different light.

It is the contention of traditional philosophy that matter cannot be explained in terms of atomism. As Aristotle argued against the atomists, "in trying to state the causes of generation and destruction, and in giving a physical account of all things, they do away with the cause of movement. And in trying to state the case further, they err in not positing the substance, i.e., the essence, as the cause of anything. . . ."[8] The method of modern physics implies the indefinite regression. If material beings have no other realities except those empirically counted and correlated, then we cannot have an atom, we cannot have matter, we cannot have a universe. This idea may also be expressed in terms of the principle of inertia. If every material being is determined here and now only by the external forces acting on it, then every being is in itself a pure potentiality. If all material beings are purely potential, then

[7] Richtmyer, F., *op. cit.*, p. 429 n.
[8] *Met.* 988 b, 26-28.

there is nothing in the material universe except the inert and the passive. The conclusion of scientific method, if in itself it is considered adequate to determine the constitution of matter, must eventually reach the absurd conclusion that it is made of nothing. In this sense, physics, unless there are realities outside of what it studies, leads to absolute nihilism. Genuine philosophy, on the other hand, while recognizing and admitting the obvious achievements of scientific method, avoids this contradiction of nihilism. It attains through its method of intellectual insight (abstraction) the realities of being, form, unity, act, value, and finality. Scientific theories are constructed to "save the facts." But if we want to "save the universe," then we must transcend the empirical level to the order of being.

In keeping with the view of a material thing as a mere sum, physics accounts for phenomena by a method of coordination and system (*ad aequivalens ab aequivalenti*). It remains, as it were, on the surface of reality without penetrating deeper down into its ultimate ontological foundations. In accounting for experience, it remains on the level of experience. Mathematics only equates (*ad aequivalens ab aequivalenti*). Equations in mathematics and physics are based on postulates that are neither mathematical nor empirical. A mathematical equation presupposes the ontological principles of being; and a physico-mathematical equation presupposes a subequational and subactional—as opposed to interactional—something which conjugates into a single unit the phenomena which physics treats as entirely partitive. Physics of itself tends to regard the world atomistically, without regard to the need for a principle of unity in being. Physics thus does not penetrate behind the mensurable wave-particles and their laws of interaction to their ontal foundations in *being*.

Being is referred to as that which is, *id quod est*. It has various meanings in the history of philosophy and in common usage. Here we may distinguish between being as considered by common sense (*ens commune*)[9] and the being of metaphysics (*ens in quantum ens*). The former notion is a primary idea.[10] Common sense rec-

[9] Cajetan, *In De Ente et Essentia*, proemium, q. 2.
[10] *de Ver*, q. 1 a. 1.

ognizes that something is. It refers to a dog, a stone, a house, as beings. But the idea of being as being is attainable only by a most difficult abstractive process.[11] The two concepts of being—the vague concept of common sense and the formal concept of metaphysical science—do not differ in kind; for nothing can be added to being in the real sense. Metaphysics deepens and purifies the plain man's notion of being and explores its reasons and relations. The idea of being as being can be grasped and studied only in abstraction from all properties pertaining to this or that thing, only when we come to examine reality in its pure character of "is-ness"; but the confused idea of being is implied in every intellectual operation. The first principles—the principles of identity, of non-contradiction, and of excluded middle—are but the considerations in judicial form of this primary idea. Every one, scientist, philosopher, and peasant has, as far as he is an intelligent being, this common idea of *ens commune*.

Metaphysics studies being as being. Being in this sense is transcendental. It rises above all determination to this or that category of reality. Disengaged from the flux and flow of the world of time and space, this being is the stark reality of that which is, that which can be, in other words existential essence. It is not measureable in terms of quantity; it itself is not quantified.

Physical science does not attain to this deep reality in the material world. Because it does not reach down to the metaphysical substructure of the world we perceive with our senses and study in such instruments as cloud-chambers, physics attains only limited aspects of reality and fails to embrace the fundamental, not-directly-qualified facts which make the aspects real.[12] But this does not mean that the scientist as a man and as a scientist is wholly out of touch with being in the general sense. An idea of being plays the fundamental role in all intellectual operations. The scientist as far as he studies *something* certainly has a notion of being. It has in fact become almost a truism to say that the empirical sciences

[11] Cajetan, *op. cit.*, proemium q. 2.

[12] "If, with science, we consider that our knowledge of the external universe can be arrived at only by a rational synthesis of facts of experience, we must recognize that substance escapes us completely; all we can hope to approach is structure or relationships," d'Abro, *op. cit.*, p. 400.

are concerned with a special kind of being. Thus biology is said to study living beings; chemistry and physics, corporeal beings; and so on. But the physical sciences do not study their objects *qua* beings. If physical science is concerned with *ens sensibile*, the accent is, as Maritain says, on the *sensibile* and not on the *ens*.[13] Being serves only as a remote material object to physics. As in the case of hylemorphism, whether literally in its application to bodies, or analogically, in its application to the form-matter character of definition by specific difference and genus as is here the case, the material serves only as an indeterminate principle. It is the determinations which flow from form that knowledge attains. In the knowledge proper to empirical physics in the widest scope of such a science, the remote material object, being, is neglected, and the formal object, corporeality, is the unique concern.

Aquinas defined being as the actuality of a thing.[14] In this point, his system stands in sharp contrast to the regressive, atomizing study of structure in contemporary atomic physics where the only realities, it was noted, are those viewed as mere recipients, acted on from the outside; mere potentialities. Being and operations are viewed as being determined by smaller partitive processes and so on ad infinitum. In the recognition of being in terms of actuality, genuine metaphysics transcends the scientific method which regards material being as purely passive and ends by reducing the universe to a vacuum. In acknowledging the reality of something that is simple, that is something one, in being, genuine metaphysics gives proof of its realism. If atomism and inertia are adequate to the plenary nature of reality, then our study of matter must end by explaining it away.[15] Such realities as actuality, undividedness, it

[13] *Les Degrés du Savoir*, p. 77.

[14] I, 5, 1.

[15] *Inertia* is being taken in the Newtonian sense of mere passivity. Relativity theory in its field concept has given a somewhat different interpretation to inertia. It has equated gravitational and inertial mass. It recognizes that in a given coordinate system, the law of inertia holds (local inertia), but the transformations (Lorentz equations) from one co-ordinate system to another cannot be made in terms of the law of inertia, which has no meaning in this sense but only in terms of the gravitational field (accelerated motion). But Relativity has no meaning on the contemporary quantum study of micro-structure; its admission of local inertia for individual co-ordinate

may be noted, are by their very being outside the ambit of scientific method. They do not, in d'Abro's sense, have "structure." They cannot be measured and reduced to mathematics. They can be studied only by intellectual insight (abstraction). Only an intellect can attain to the actuality which is being. Only the power of a simple substance is adequate to grasp the undividedness.

But if every intellectual activity presupposes a notion of being and if the physicist does not attain to being as being, it may be asked what conceptual basis is employed in physics to represent the "structure" of the universe. What corresponds in the real world to the *something* envisioned by atomic physics? Perhaps it can be called schematological being as opposed, if the pleonasm will be pardoned, to the ontological being of metaphysics. Why it should be so-called may be argued from the atomizing character of modern physics in which matter, in its ultimate make-up, is regarded as a mere lattice-work of wave-particles where the dynamic, infra-atomic phenomena are accounted for by *ad hoc* explanations that must continually be multiplied like the particles themselves. If physics pulverizes reality, it does not, as physics, attain to a true conception of being in the conceptual framework it employs for working operations. Plurality is opposed to entity as a contrary opposite because being is one.[16] This is additional proof that physics, because it pluralizes matter, does not attain to matter's ultimate reality, its being-ness. The account which physics gives of microstructure (and therefore of the macrostructure which is reducible in physics to the study of subatomic particles) is only a *schema* of the real.[17] This is the reason for the term *schemato-*

systems brings it, as far as the purely empirical aspects of physics are concerned, under the same laboratory treatment as any inertial system. *Inertia*, as a physical concept, need not refer only to local motion as in Newton's first law but to the scientific view of a thing as having no actuality in itself but as being completely determined from the outside. The theory of relativity accepts this view for local systems.

[16] I, 11, 1 ad 2.

[17] Riezler says in his imaginary dialogue of Aristotle with the modern physicist: "These distinctions, transplanted from their native soil to your scheme of nature, would lose their interconnection and correlation in the notion of substance. Separated from substance they become separated from one another and can no longer say what they want to say—like single letters which have lost their word," *op. cit.*, p. 105.

logical, to characterize the concept of being that the physicist must logically accept as a physicist, obedient to his atomizing method.

The unity of being may be thought of in two ways, corresponding to the two references it has in reality. It may be the transcendental unity of being as being, or the predicamental unity in the order of quantity. Predicamental or categorical unity is the principle of number and is found in every being as far as it is this or that *determinate* (i.e., categorical) being in the material order. It adds something real to the determinate being. It is the basis for enumeration and also classification.[18] Modern physics may be likened to ancient Pythagoreanism. With its tendency to disregard all but the mathematical aspects of the real, it is formally occupied with this predicamental or categorical unity. Here indeed lies a principal reason for its circumscribed character.

Transcendental unity, on the other hand, pertains to being as being. It is defined as the undividedness of being itself.[19] Nothing can be added to being which is not already included in being. Unity expresses a general mode of being, the negation of division.[20] That unity is convertible with being is proved by Aquinas in a very simple but forceful fashion. All being is either simple or composite. If it is simple, it is already one. If it is composite, then it does not have being so long as its parts are divided but only when they are put together. This may be exemplified by the instance of a house. As long as the stones and other structural units are not put together, the house is not a being. It is only a being when put together.[21] Aquinas hints that this is only a figurative example since the house is an artifact. The unity of being is "like" a house. A house is an aggregate. It is not a per se unity. Nevertheless, the example suggests in its own way the deep metaphysical meaning of *Ens et unum convertuntur*. The realities of potentiality and actuality shed clearer light on the fact that transcendental unity does not add a real determination to being but *is* being itself when the mind inspects it from the viewpoint of its undividedness. If we example being as it is in man, we find it to be a composite of

[18] I, 11, 1.

[19] I, 30, 3.

[20] *In Met.* IV, 21.

[21] I, 11, 2 ad 2.

animality and rationality. Neither constitutes man itself. Nor does each possess a unitary self-subsistent character in the composite. The animality of man is not terminated in itself as the unity of a dog or horse. In man, animality is indeterminate when considered in itself.[22] It is subsumed as a potential principle in the species man. It is only when so actuated that man, the substantially united rational animal, becomes a being.

From the fact that being is one, it is apparent that being, for the physicist as such, is not the deep transcendental reality studied by the science of metaphysics. The physicist's account of the world is not ontological. It pluralizes being. It presents only a schema. The physicists may assert that they do not make pictures or models in the exact sense. But here the question is not the physicist's working representation of reality but the way reality is representable according to the method of physics. Obedient to its atomizing nature, physics must regard its units as composite things held together by unifying forces (superadded to being and not convertible with it). With ever more refined technique, it is possible that the ultimate particles will themselves be "smashed" like the atoms. So *ad infinitum*. Aquinas, in a passage remarkably adapted to this problem, declares: "If a being were one in virtue of something else and if this unifying something which is also one, were one in virtue of still something else, the process would go on ad infinitum."[23] Being is one by its nature, not in virtue of additions. As Riezler states in his imaginary dialogue of Aristotle with the modern physicist: "The little word 'is' has a double meaning. Corresponding to this double meaning are two senses of the word 'nature.' First yours: the order of Many in time and space, nature as a world. Then mine; nature as 'Physis,' the structure of concreteness so far as the concrete is concrete, nature as Being: Physis, born together, as Plato says."[24]

We cannot claim to have found the simplest particles of matter in the units so common in the vocabulary of contemporary science. All we can say is, in the words of Millikan, *"There has appeared*

[22] *de Pot.* 9, 4.
[23] I, 11, 1.
[24] *Op. cit.*, p. 60.

up to the present time no evidence for the existence of a subelectron."[25] But until the end of the nineteenth century, the atom itself was thought to be indivisible. All this shows the typically changing character of scientific ideas. Physics is like a serial story that reaches climax in each installment but never comes to a final conclusion. Because we cannot make the divisions in matter, it does not follow that a given particle is indivisible, for the so-called ultimate particles have, in d'Abro's language, structure. Hence being for the physicist, prescinding from the ideas which he might have as a man, is divided being (*ens divisum*)—a contradiction in terms if fully analyzed. It is not the true being of metaphysics. It is schematological.

Unity, undividedness, act elude the scientific method. Physics studies material realities which are composite unions in themselves. But it studies these realities not as they are unities but as they are composites. Unity, as such, escapes scientific technique because it, like being, does not derive its reality from another determination (it is in itself convertible with being). Being and its attributes (which are really identical with being but differ only logically, as far as we look at being in different ways) cannot be discussed in terms of addition and subtractions. Science can only study that which is definable in terms of superadditions, that which is, in itself, inert, deriving its reality from the outside. It cannot study being. It cannot study unity. Its conceptual system does not reach being as being but only a *schema* of reality. Compared to the fullness of the real, the conception of reality, according to the method of physics, is, in a simile suggested by Aristotle, like a string of syllables that are considered apart from the word they form.[26] Such an appraisal of the conceptual structure of physics does not mean that scientific theories and constructs are wholly out of contact with reality. It was already noted that they have a material correspondent in the real world. But the scientific method does not exhaust the riches of reality. It does not reach the ultimate principles of the real which exist on a level which physics cannot attain.

True knowledge should proceed from the complex to the simple.

[25] *Op. cit.*, p. 181.
[26] *Met.* IV, 1014 a 30-31.

Philosophy begins with the discrete data of sense and ascends to the unity of being itself. But being as being, the object of metaphysics, is not simple under every aspect when regarded as an analogue. If it leaves room for the projection of the analogates, it has an aspect of complexity. Aquinas speaks of the references between analogue and analogates as being partly the same and partly different.[27] The expression "partly" may be misleading if given spatial significance. But perhaps this difficulty proceeds more from language than from thought since we must necessarily express all our concepts by means of ideas, either affirmative or negative, borrowed from the sensible order. As far as each analogate has reference to the same analogue, we preserve the unity of being. But as far as each reference differs, beings can be diversified and multiplied, and pantheism can be refuted. But if being as being is analogical, it is primarily one and only secondarily (an analogically) complex. The schematological being of science, on the other hand, is primarily multiple, so to speak, and only secondarily one—one, that is, because only in terms of mental unity can the mind understand the multiple.

To specify this or that apparently unified being in the inorganic world as bearing substantial unity is another and far more difficult question. Do the elements differ from one another merely by the addition and subtraction of nuclear particles? Does the proton, if it is a composite of neutron and positron, differ specifically from the parts that make it up; or is it a mere mechanical aggregate of its component parts as the physicist would describe it? The physicist, as such, can rightly refrain from pronouncing on the character of the composition in the matter he studies. Such a question is beyond the compass of his science. On the other hand, the philosopher because of the evidence available in the present status of atomic physics, may not be able to determine whether the parts of an atom (or proton, etc.) are substantially or only accidentally united. In order to study the electron, the neutron, the proton, the physicist must remove it from its natural context within the atom. Hence by the very conditions of the problem, the philosopher cannot decide the question of the relation of the particles to the whole of the atom.

[27] *In Met.* IV, 1.

Do they become subsumed under a formal character in an element, losing their identity in the potentiality of matter? Or are they mere mechanical parts of an accidental union, like the bodies of the solar system?[28] Eddington has asked the question whether the electron is discovered or created, whether the scientist takes reality as it is, or shapes it as a sculptor carves a statue out of marble.[29] Though Eddington aims to establish by his argument that knowledge is *a priori*, his question is not wholly meaningless even for the realist in philosophy. We cannot speak of the creation of an electron from matter. But we may well bring about a change in the constitution of an atom so that the electron which was potentially an electron in its status within the substantial unity of the atom, now becomes actually an electron, a whole in itself and no longer a part. The attempt to interpret present-day atomic physics entirely as a partitive mechanical aggregate, like the solar system, is based upon analogy and is subject to its logical pitfalls. "A model of this kind, for example, a system of mechanical, wave, or vortex motions, implies inexact or incomplete argument by analogy from a macroscopic to a different *microscopic* situation."[30]

A decision on this mooted question is not essential to present purposes. If the atom is a substantial union or not, if the proton is a mechanical aggregate or not, it is sufficient to have established that somewhere within the matter studied by scientific method there is the being, the unity, the actuality, the undividedness which escapes physics but without which the cosmos would be emptied of the real. Since this being is a material being, its quantity may be further divided, because quantity, as such, is indefinitely divisible. But its being cannot be divided without changing it into something else.[31] If an atom may be considered, by way of mere example, to be a substantial union, it may, as far as it is quantified, be indefinitely divided. But when we divide the parts from one an-

[28] The philosopher need not necessarily indicate the level of reality, molecular, atomic, or subatomic, where form appears. It suffices to show that, if the macroscopic world is mechanical, we eventually, in breaking it up, come to a point where mere mechanism is insufficient and where form must be recognized.

[29] *The Philosophy of Physical Science*, pp. 106 ff.

[30] Whyte, L., *op. cit.*, p. 122.

[31] *de Pot.* IV, 1, ad 5.

other, we may, as we see in the phenomenon of atom-smashing, change the nature of the original atom so that it becomes an atom of a different element.[82] A certain minimum of quantity would be necessary to preserve the substantial unity of such a being, and the indefinite division in the order of quantity as such, changes the nature of the atom and perhaps also, if the division is carried far enough, the nature of the subatomic particles.

In cases of substantial union between parts, new species are not formed by mere addition of mechanical parts to mechanical parts but by substantial changes. For the substantial being of a thing is indivisible.[83]

Indivisibility cannot be studied by scientific method. Physics can only attain to the inert, the quantified, the divisible. For physics differences between realities are additive, and quantified, not specific and substantial. In our present knowledge of particle phenomena, we must isolate the fundamental units before we can study them. Their nature as part of the atom is not amenable to scientific method. Though by the very terms in which the problem is stated, one cannot expect the physicist to determine the relationship of electrons, waves, neutrons, and exchange-forces, and so on, within the atom itself, for the very same reason we cannot follow along with the physicist in his reduction of the atom to mere partitive phenomena.[84] It is only of importance to establish here that there are realities which the physicist, as such, does not attain and which are guarantees against the nihilism of the method of atomic physics, if it alone is adequate to the real. As Riezler has written to the contemporary physicists: "If you expect your concepts to reach the realness of reality, they ought to be conjoined as a whole in a logical structure that shows each concept as one-to-others. Such a logic builds up concreteness; wherever you meet concreteness you have to do with such a structure. I might say: your concepts have to grow together—*concrescere*. If they did, your world would no longer lack reality. But they cannot. A link is missing—substance."[85]

[82] *In Met.* V, 15.
[83] I, 76, 4 ad 4.
[84] I, 76, 3 ad 4.
[85] *Op. cit.*, p. 74.

If there are in the world of matter beings which are one and substantially one, then there is a principle in each substantially different being which makes it to be what it is and which cannot be reduced to the mere addition of particles in the realm of the quantified. For this principle which makes a thing to be what it is cannot be itself determined and dependent (like the inert, passive realities which are conceived by physics). It is a principle which is not determined but determining, not inert but active, not quantitative but simple and indivisible.[86] This is entelechy or form.[87] It is the principle of perfection in matter, the principle of union, a principle of intelligibility and not of number and quantitative measurement. It is not superadded to an already actualized matter, as the Drieschian entelechy is superadded in a living thing to the mechanical energies. Nor it is not compounded with matter as sodium combines with chlorine to form salt. The problem of hylemorphism is not on the empirical level. It can neither be raised not settled by pointer-readings.

Opposed to the actualizing entelechy or form is a potential substrate, the thing that the form determines. Because it must be united immediately to the form and not, as a mechanical union would have it, through a medium that would, as in physics, involve us in an infinite regress, because of this immediacy, the potential substrate has no actuality of its own, apart from the entelechy. Hence, there can be a substantial union—a union that is on a different level from the mechanical aggregation which physics believes to exist in compounds and in atoms.[88] The empirical physics of

[86] "Et forma, per quam unaquaeque res continetur in suo esse *terminus* dicitur," *In De Div. Nom.*, 1, 2, 3. (Italics are mine.)
[87] The English word "form," like the Latin "forma," does not convey the thought of traditional philosophy in speaking of substantial form. The original Greek term, ἐντελέχια, entelechy (ἐν τελει ἐχειν to be complete) is much clearer. The term, entelechy, has been popularized by Driesch in psychology. In this context, the name has acquired an unfortunate meaning which is not in accord with Aristotelian concepts nor with the reality designated by the word "form." However, despite its confusion, entelechy is perhaps less awkward in English as a rendering of "forma substantialis" which conjures up, in an age accustomed to quantity, the connotation of spatial figure and shape.
[88] *In Met.* VII, 2.

Aristotle has been jettisoned by the facts discovered and the theories advanced in the modern science of physics. But man's mind is challenged today by the same dilemma that confronted Aristotle and his master, Plato—the problem of the bifurcation in matter. We observe in material beings inertia and activity, quantity and quality, extension and indivisibility, flux and permanence, corruption of individuals and the recurrence of a type or species. Whitehead has perceived this problem, viz., "that there is an essential atomic property in nature which is independent of the dissociation of extension. There is something which in itself is one, and which is more than the logical aggregate of entities occupying points within the volume which the point occupies."[39] He recognizes that there are so-called "prehensive" and "separative" characters in the world, the limitations of things by their "modalities." But his philosophy of organism is monistic and even pantheistic. Aristotle's answer was dualistic.

The method of physics cannot study the entelechies of material things. It cannot study substantial composition. It can neither accept nor reject the idea of a primary substantial substrate. Its work is carried out on a different level from that of the philosopher with his analytico-synthetic method of intellectual insight. Entelechy is a terminus. The physicist cannot find meaning in this idea. It does not have structure. It is not determined by something else, acting on it as on an inert passive body. Substantial differences are not matters of addition of particles in the mechanical sense. Entelechy as such is not the result of juxtaposition as such. It is educed from the potentialities of the substrate.[40] As Aristotle wrote, "But we maintain that if 'combination' has taken place, the compound *must* be uniform in texture throughout—any part of such a compound being the same as the whole, just as any part of water is water; whereas if 'combination' is composition of the small particles, nothing of this kind will happen."[41] If the physicists reject the scientific view of Aristotle that water is a compound in the sense described, the philosophical view of substantial combination re-

[39] *Concept of Nature*, p. 23.
[40] I, 66, 1.
[41] *On Gen. and Corr.*, 328 a, 10-13.

mains unchanged. Somewhere within the particles studied by physics, whether it be on the level of the macroscopic bodies, of molecules, of atoms, or of subatomic particles, this substantial composition exists. The philosopher may not be able to put his finger on the level of reality where we can no longer discover accidental unity in things but must come to that higher, inner, active unity that flows from form. But he can say with certitude that somewhere down in the deep reaches of matter this unity, this form, this entelechy, this non-inertial reality resides.

It is the reality of this entelechy or form that saves matter from the infinite mechanical regression which would render it a void. As Aquinas in following Aristotle remarks, "Substantial form is not only the perfection of the whole but of every part."[42] It confers being by its immediate union with matter. There is no indefinite mediation of particles and forces as we have in modern physics, both in method and result.[43] "Form by itself renders a thing actual, since by its essence it is not act, nor does it confer being through a medium."[44]

The immediacy, the termination, the directness of form evades the technique of physics. Entelechy, because it is immediate, can only be grasped by the faculty of immediation, viz., abstraction. Abstraction directly apprehends reality without the middle term and without the enumeration which are demanded by physics. As Aquinas says, between the individual and the species, there is no middle term.[45] An immediate thing does not have what d'Abro calls "structure." It cannot be apprehended by physics. It can only be attained by abstraction.

Because entelechy confers being, because it combines with the primary potential substrate to form a reality which is the same in its whole and in its parts, entelechy also confers unity.[46] Such a unity, which is not a mere mechanical aggregation, is made possible by the fact that one of the principles is purely potential.[47]

[42] I, 76, 8.
[43] I, 76, 4.
[44] I, 76, 7.
[45] Cf. *supra*, p. 134.
[46] *Quodl.*, I, 6.
[47] *In Met.* VIII, 5.

Quantitative parts are present within such a unity. But they are present as parts. Division is necessary to render them wholes. Until then they do not bear an actual existence as something definite and distinct in themselves.[48] It may be affirmed only that the quantity in such a unified being is divisible. It is not actually divided. Quantity may be divisible *ad infinitum*. But it is never actually so divided. This terminus is a substantial being, this undividedness in quantity and indivisibility in being is supplied by the entelechy. There must be immediation in such a being. With the mediation of parts and forces, there would be an infinite regress.

Such an infinite regress results if we equate reality and the subject-matter of physics. Thereby we negate reality altogether. There could, as Aquinas says, be no knowledge either. It is form or entelechy that unifies matter and makes it intelligible.[49] As Plato noted, if the one (unity) does not exist, then nothing can be or be conceived.[50]

Only in the plenitude of being which embraces everything that exists or can exist do we have a science of totality, a science of that which is. Recognizing limits where limits exist, the philosopher does not lay claim to an exhaustive knowledge of the infinite recesses of being, of unity, and of form. But his knowledge which grows by an *intensive*[51] deepening of the universal whole has already brought him into contact with reality's farthest depths. He is truly in the order of the ultimates. His knowledge, however, is imperfect because incomplete. The physicist on the other hand, whose knowledge grows by an *extensive* passage from part to part does not touch the level of being, of unity, and of form. He deals only with mediations, never with immediacies. His knowledge is imperfect, not, because it is incomplete in its own order, but because the very empirical order itself is not adequate to reality, being, unity, and entelechy. His knowledge is not only imperfect in degree but also in kind. The schematological being of the science

[48] *In Sent.* IV, d. 10, 1, 3 ad 3 sol. 3.
[49] *I Anal. Post.* 36.
[50] *Par. op. cit.*, p. 140.
[51] Maritain, J., *Sept Lecons sur l'Etre*, pp. 5 ff.

of physics, while having a real counterpart in nature, is not the ontological being of the science of metaphysics. If it is transferred to the level of ontology, it becomes an *ens divisum*, a contradiction in terms, like a square circle.

Galileo has won his battle with Aristotle in the modern mind, trained as it is to regard scientific method as the only technique of study and the subject-matter of physics as the only reality. But such an attitude over-simplifies the cosmos and fragmentizes knowledge. Galileo and Aristotle can join hands if we look to principles. By making distinctions where distinctions exist, we can have both modern empirical science and the traditional sciences of metaphysics and cosmology. The method of modern physics in theory and in practice has given the modern mind both knowledge and practical achievements hitherto undreamed of. Yet it has clear-cut philosophical frontiers within which it will continue to advance but beyond which it may not go. It is only to be reasonable, it is only to be realistic, to recognize limits imposed by the nature of things. When that is done, the disputed frontiers between science and philosophy will no longer be the battle ground they now are. The poet, philosopher, and the scientist can again work together.

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